DATA CENTER ENERGY BENCHMARKING CASE STUDY

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FACILITY 9

Sponsored By:

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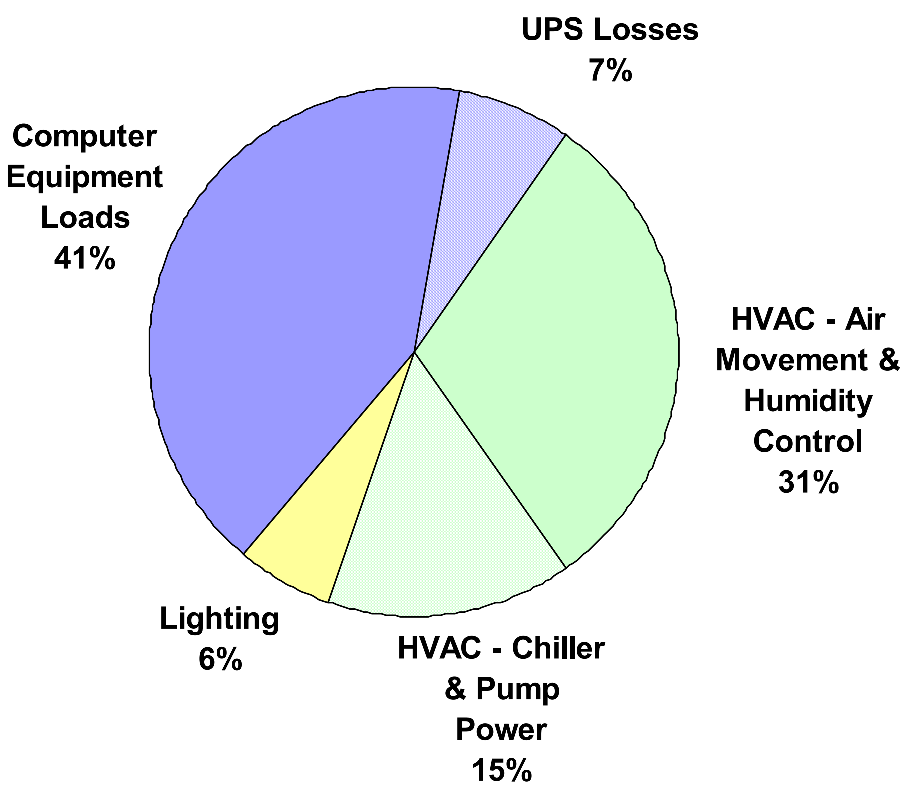
I. Executive Summary

Rumsey Engineers and the Lawrence Berkeley National Laboratory (LBNL) have teamed up to conduct an energy study as part of LBNL's Data Center Load Characterization Project. This study is intended to help designers make better decisions about the design and construction of data centers in the near future. This report describes the analysis of a data center in Sacramento, California. Measurements were conducted on-site from January 6 to 8, 2003, with the particular aim of determining the end-use of electricity. The identity of the organization that owns this data center is kept anonymous. The facility that houses the data center is referred to throughout this report as Facility 9.

The report begins with definitions of some basic terms. This is followed by an overview of the data center and the cooling system that serves it.

Section IV, Energy Use, is the main focus of the report. It is sub-divided by equipment type – UPS, data equipment, cooling system, and lighting. The electric power consumed by the equipment, and notable equipment behavior, is examined in detail. The section concludes with summaries and metrics. The following chart is an example from the summary.

Figure 13. Data Center Energy Balance



The report concludes with recommendations for saving energy at Facility 9, some general and some specific. The two chilled water plants examined in this study are due for removal in early 2003; Facility 9 will obtain chilled water from a new central plant that will serve several buildings. Given these circumstances, the specific recommendations in this report focus on the data center itself, and not the existing chilled water plants. The specific recommendations address humidity control, effective computer cooling, and lighting.

II. Definitions

Air Flow Density — The air flow (CFM) in a given area (ft^2 or sf)

Chiller Efficiency — The power used (kW), per ton of cooling produced by the chiller.

Computer /Server Load Projected Energy Density — Ratio of forecasted Data Center Server Load in Watts (W) to square foot area (ft^2 or sf) of the Data Center Floor if the Data Center Floor were fully occupied. The Data Center Server Load is inflated by the percentage of currently occupied space.

Computer Load Density – Rack Footprint — Measured Data Center Server Load in Watts (W) divided by the total area that the racks occupy, or the rack "footprint".

Computer Load Density per Rack — Ratio of actual measured Data Center Server Load in Watts (W) per rack. This is the average density per rack.

Computer/Server Load Measured Energy Density — Ratio of actual measured Data Center Server Load in Watts (W) to the square foot area (ft^2 or sf) of Data Center Floor. Includes vacant space in floor area

Cooling Load Density — The amount of cooling (tons) in a given area (ft^2 or sf)

Cooling Load Tons — A unit used to measure the amount of cooling being done. Equivalent to 12,000 British Thermal Units (BTU) per hour.

Critical Load — Electrical load of equipment that must keep running in the event of a power failure. Such loads are typically served by an Uninterruptible Power Supply (UPS), that uses a bank of batteries to support the load when the normal source of power fails. The batteries can support the load for only a short period. In some facilities the equipment is shut down gracefully and turned off until normal power returns. In other facilities a backup generator, typically diesel-powered, comes on-line and provides power for a longer period of time.

Data Center Cooling — Electrical power devoted to cooling equipment for the Data Center Floor space

Data Center Facility — A facility that contains data storage and processing equipment (servers) associated with a concentration of data cables.

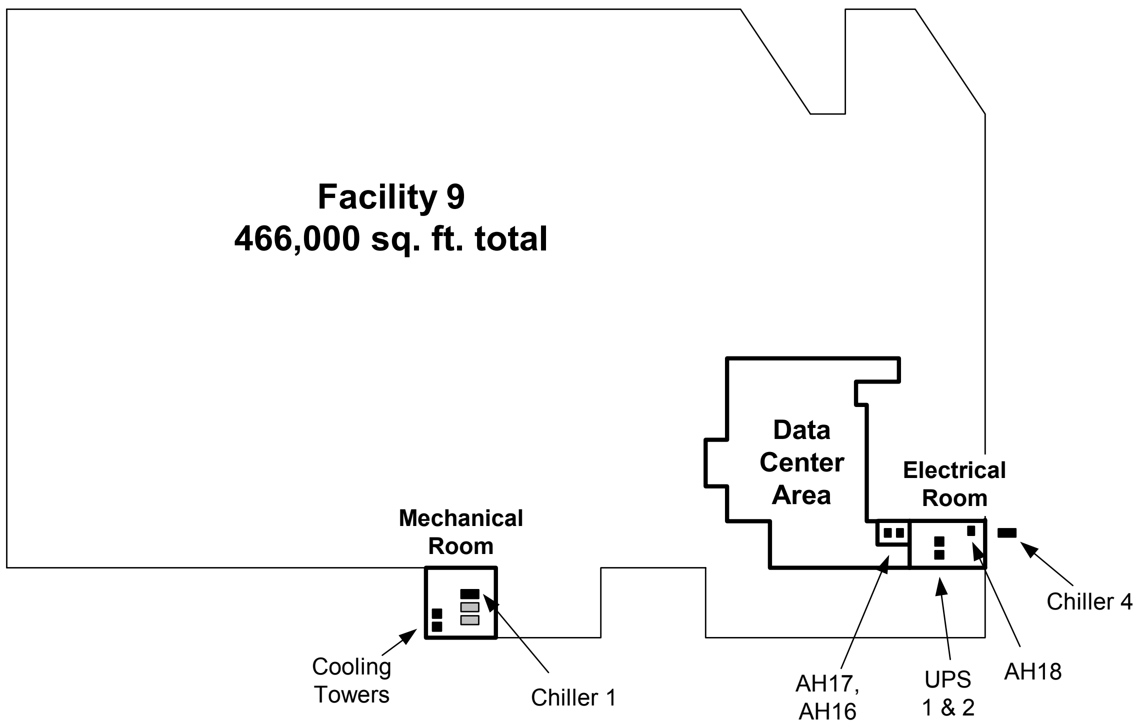
Data Center Floor / Space	Total footprint area of controlled access space devoted to company/customer equipment. Includes aisles, caged space, cooling units, electrical panels, fire suppression equipment, and other support equipment. Per the Uptime Institute Definitions, this gross floor space is what is typically used by facility engineers in calculating a computer load density (W/sf).[1]
Data Center Occupancy	This is based on a qualitative estimate on how physically loaded the data centers are.
Data Center Server/Computer Load	Electrical power devoted to equipment on the Data Center Floor. Typically the power measured upstream of power distribution units or panels. Includes servers, switches, routers, storage equipment, monitors, and other equipment.

[1] Users look at watts per square foot in a different way. With an entire room full of communication and computer equipment, they are not so much concerned with the power density associated with a specific footprint or floor tile, but with larger areas and perhaps even the entire room. Facilities engineers typically take the actual UPS power output consumed by computer hardware and communication equipment in the room being studied (but not including air handlers, lights, etc.) and divide it by the gross floor space in the room. The gross space of a room will typically include a lot of areas not consuming UPS power such as access aisles, white areas where no computer equipment is installed yet, and space for site infrastructure equipment like Power Distribution Units (PDU) and air handlers. The resulting gross watts per square foot (watt/ft2-gross) or gross watts per square meter (watt/m2-gross) will be significantly lower than the watts per footprint measured by a hardware manufacturer in a laboratory setting.

III. Site Overview

All of Facility 9 is housed in a single, 466,000 square-foot building; see Figure 1.

Figure 1. Facility 9 Site Plan



On their web site (http://datacenters.lbl.gov/What.html), LBNL defines "data center" as follows:

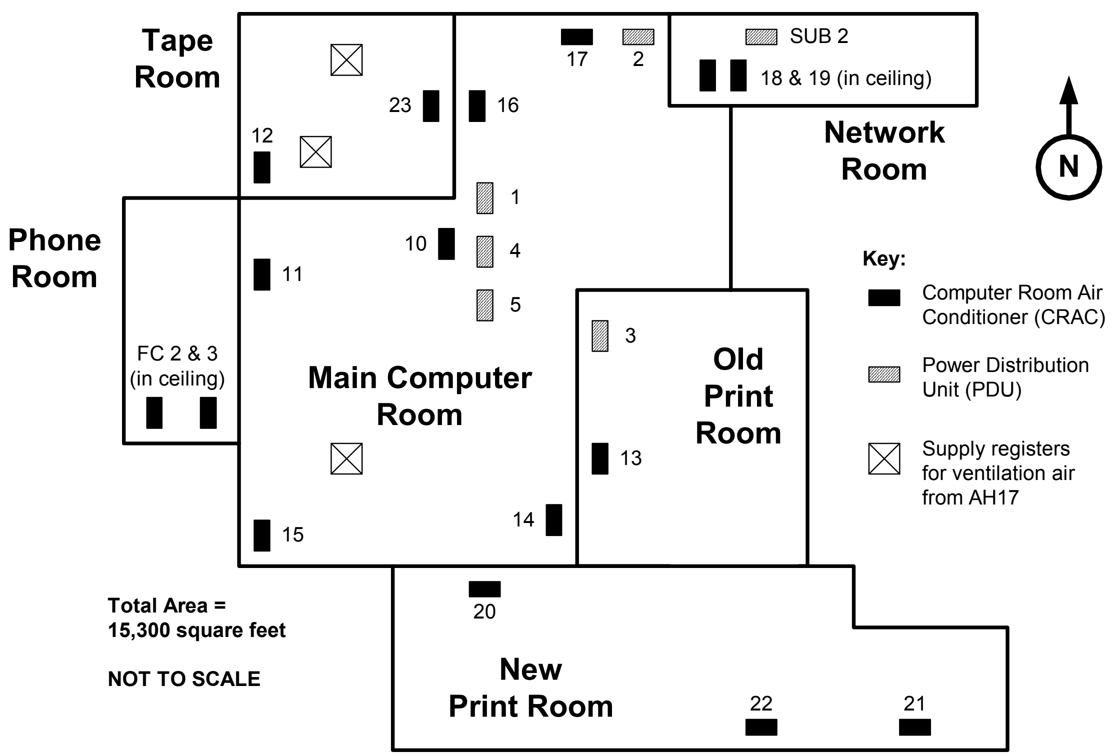
> "We define a data center as a special facility that performs one or more of the following functions:
> - Store, manage, process, and exchange digital data and information;
> - Provide application services or management for various data processing, such as web hosting internet, intranet, telecommunication and information technology.
>
> We do not consider spaces that primarily house office computers including individual servers associated with work stations as data centers."

For this report, we treat the entire area shown in Figure 2 as a single data center. It comprises about 3% of the total building area. This data center is the focus of this report.

The data center contains six rooms. The Main Computer Room houses the facility's primary data processing servers. The Network Room is dedicated to the building's computer network servers. The Old and New Print Rooms contain large, continuous-feed printers. Six robotic memory-tape silos are installed in the Tape Room, and the telephone switching equipment is found in the Phone Room.

All of the computer and printer equipment loads in the data center are served by six Power Distribution Units (PDUs) located in the data center. All the PDUs are served by a pair of uninterruptible power supply (UPS) systems located in the electrical room.

Figure 2. Data Center Floor Plan



The data center is cooled primarily by twelve floor-mounted Computer Room Air Conditioning (CRAC) units.[2] In addition, there are two fan coil units and two more CRAC units mounted in the interstitial space above the ceiling tiles. The CRAC units are capable of humidity control; the fan coils are not. Makeup air for the data center is provided by air handler AH17. All fourteen CRAC units, the two fan coils, and air handler AH17 use chilled water for cooling. All seventeen units serve only the data center.

[2] Facility 9 uses the term CAC instead of CRAC. This report uses the term CRAC, to be consistent with reports on other data center facilities.

The Main Computer Room, Tape Room, and the Old Print Room have raised floors, consisting of 2-foot by 2-foot tiles approximately 1 foot above the underlying slab. Most of the tiles are solid, but approximately 10% of them are perforated and distributed across the floor area.

In these raised floor areas, the CRAC units supply air directly to the underfloor space. Air rises through perforated tiles, and returns through grills located in the top of the CRAC units.

In the areas without a raised floor, the CRAC units deliver air upwards. The air is ducted up to the space above the ceiling tiles, and then the duct branches to several ceiling supply registers. Likewise, the fan coil units installed in the ceiling deliver their air via ducts and ceiling supply registers.

Air handler AH17 is housed in a small room between the data center and the electrical room. The makeup air from this unit is delivered to three ceiling supply registers – one in the Main Computer Room, and two in the Tape Room.

All of the floor-mounted CRAC units are capable of humidity control. The ceiling-mounted units do not have humidity control. Humidification is provided by electric humidifiers, and reheat for the dehumidification process is also electrical.

Table 1 lists the basic specifications of all the CRAC and fan coil units.

Table 1. CRAC and Fan Coil Unit Descriptions

Label	Room	Make	Nominal Cooling Capacity (tons)	Has Digital Display	Floor/ Ceiling Model	Air Flow
CRAC-10	Main Computer	Liebert	20	yes	Floor	Down
CRAC-11	Main Computer	Liebert	20	yes	Floor	Down
CRAC-14	Main Computer	Liebert	20	yes	Floor	Down
CRAC-15	Main Computer	Liebert	25	yes	Floor	Down
CRAC-16	Main Computer	Liebert	25	yes	Floor	Down
CRAC-17	Main Computer	Liebert	25	yes	Floor	Down
CRAC-18	Network	Liebert	5	no	Ceiling	Side
CRAC-19	Network	Liebert	5	no	Ceiling	Side
CRAC-13	Old Print	Liebert	20	yes	Floor	Down
CRAC-20	New Print	Liebert	5	yes	Floor	Up
CRAC-21	New Print	Liebert	5	yes	Floor	Up
CRAC-22	New Print	Liebert	20	yes	Floor	Up
CRAC-12	Tape	Liebert	10	yes	Floor	Down
CRAC-23	Tape	Liebert	10	yes	Floor	Down
FC-2	Phone	?	?	no	Ceiling	Side
FC-3	Phone	?	?	no	Ceiling	Side

Chilled water is distributed to all the CRAC and fan coil units, and to the make-up air handlers, by a chilled water pipe loop. Chilled water is introduced to the loop from two different chillers. See “Cooling System” under Section IV of this report for a description of the chilled water plants.

The entire HVAC system is controlled and monitored by a Barber Coleman Network 8000 system.

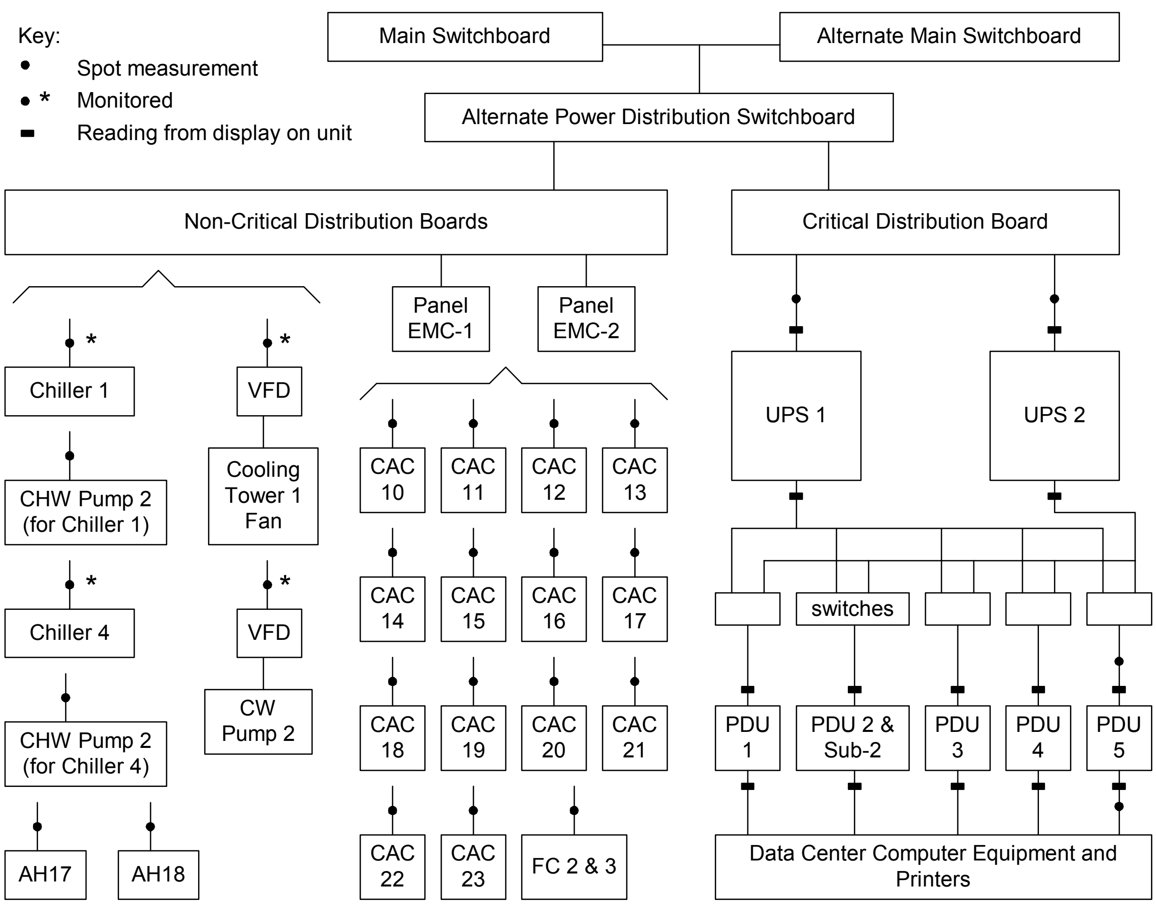
Both the main chilled water plant and the air-cooled chiller were due for removal shortly after the measurements for this study were completed. A new building is being added to the site. All the buildings on the site will be served by a new, central chilled water plant.

IV. Energy Use

Data Center Facility 9 is served by two utility substations. If one substation fails, the other substation picks up the load. If both substations fail, the UPS system supports the critical load for about 100 minutes, permitting a graceful shutdown of the computer equipment. There is no on-site power generator.

All of the computer and printer equipment in the data center is considered critical load, and is served by the UPS system via the PDUs. The HVAC equipment is considered non-critical load. Figure 3 is a simplified electrical diagram that shows the points of measurement. A Powersight PS3000 clamp-on power meter was used for all spot measurements and for longer periods of monitoring. The UPS units and the PDUs are equipped with digital display panels that indicate input and output load.

Figure 3. Electrical Measurement Points



UNINTERRUPTIBLE POWER SUPPLY

Two 500 kVA Liebert model UDA63500A36A uninterruptible power supply (UPS) units provide power to the critical loads in the data center. The UPS converts alternating current to direct current and charges a battery bank. Direct current from the batteries is converted back to alternating current and is fed to the data centers.

Based on the current total data center load, either UPS has sufficient capacity to serve the load by itself. Both UPS units operate continuously, however; this is required to keep both battery banks charged. The power supplied to and from the UPS was measured to determine how much of their capacity is being used, and how efficiently they are operating.

Table 2. UPS Electrical Measurements[3]

	Units	UPS 1	UPS 2	Combined
Input	kW	227.1	35.8	262.8
Output	kW	203.5	17.0	220.5
Loss	kW	23.6	18.8	42.3
Efficiency	%	89.6	47.3	83.9
Load Factor	%	40.7	3.4	16.8

Figure 4. UPS 2

[3] Input and output values are spot readings of the UPS on 1/7/03. See Appendix B for details of the measurement process.

The measurements show that UPS 1 has a higher load factor than UPS 2 (40.7% vs. 3.4%), and is operating much more efficiently (89.6% vs 47.3%). The data center manager stated that this is a temporary condition; normally the UPS systems are loaded equally.

DATA EQUIPMENT

The data center consists of six rooms. The Main Computer Room contains server racks, tape drives, tape shelves, and several workstations. The computer equipment is arranged close together in the north end of the room, and less so in the remainder of the room. See Figure 5.

Figure 5. Main Computer Room

The Network Room contains two rows of server racks, that nearly fill the entire room. The Old and New Print Rooms contain large, automated printers. The Old Print Room is approximately 80% full of equipment, and the New Print Room is about 30% full. See Figures 6 & 7.

Figure 6. Old Print Room

Figure 7. New Print Room

The Tape Room contains six large, vertical cylinders that house robotic tape drives. There is no space to add additional units of this type. A photo of this room appears on the cover of this report. Finally, the Phone Room is full of racks of phone switch gear.

All computer equipment in the data center receives power from one of the five PDUs. The PDUs receive power from the UPS and remove spikes and transients.

Figure 8. PDU-4

All the PDUs have a 125 kVA nominal capacity. All of the PDUs are equipped with a digital display. To ascertain the accuracy of these displays, the input of PDU-5 was measured directly. PDU-5 was chosen over the others as it was the most accessible of the units. The results are shown in Table 3.

Table 3. PDU-5 Measurements

	Time of Day, 1/7/03	Source of Data	Power	Power Factor	Effic.	Load Factor	Loss
			kW	--	%	%	kW
Input	17:21	Powersight PS3000	19.49	0.96	94.8	13.0	1.0
Output	17:37		18.48	0.97			
Input	17:40	PDU Display Panel	n/a	n/a	n/a	n/a	n/a
Output	17:40		18	1.00			

Even though PDU-5 was only 13% loaded at the time of measurement, it was running at 94.8% efficiency. High efficiencies are typical of this type of power conditioning equipment. The display panel readings show close agreement with the directly measured values.

To obtain the total load served by the PDUs, all the PDU display panels were read within a 14-minute period on 1/8/03 as shown in Table 4.

Table 4. PDU Readings[4]

Label	Output Power (kW)	Power Factor	Load Factor (%)	Time
PDU-1	30	1.0	24	11:06
PDU-2	65	1.0	52	11:09
PDU-3	47	1.0	38	11:16
PDU-4	25	1.0	20	11:04
PDU-5	19	1.0	15	11:02
Combined	186	--	30	--

The total electrical load served by the PDUs was 186 kW at the time of measurement. This represents 30% of the total nominal capacity of the PDUs.

As a check on the total PDU load, the output of the UPS units was read from the UPS display panels less than 2 hours later. The readings are shown in Table 5.

[4] All readings taken on 1/8/03 from PDU displays. PDU-2 is actually two units: PDU-2, and PDU-Sub-2. The latter serves the Network Room, and does not have a display panel. The display panel on PDU-2 reports the total power for both units.

Table 5. UPS Readings[5]

Label	Output Power (kW)	Load Factor (%)	Time
UPS 1	173.5	35	12:58
UPS 2	16.5	3	12:58
Combined	190.0	19	--

The total output of the UPS units is in good agreement with the PDU readings. Note that the total UPS output is less than was observed on the previous day, as shown in Table 2. The measurement team observed that the UPS output fluctuated somewhat during the period of measurement; this is likely due to the large printers cycling on and off.

[5] Readings taken on 1/8/03.

COOLING SYSTEM

CHILLED WATER PLANTS

The CRAC units, fan coils, and three air handlers receive chilled water from a distribution loop; see Figure 11.

Chilled water is introduced to the distribution loop from two sources. The first is the main chilled water plant consisting of three, water-cooled centrifugal chillers. Only Chiller 1 ran during the period of measurement; it is a Carrier 150-ton unit. According to the maintenance crew, Chillers 2 and 3 do not run during the winter months. The maintenance crew says that all of the chilled water produced by Chiller 1 during the monitored period served only the data center. These statements are in keeping with observations made by the measurement team. As discussed below, the office space served by air handler AH16 received all of its cooling via air-side economizing, and did not require any chilled water.

The second source of chilled water is from a 100-ton Carrier 30GT air-cooled reciprocating chiller, installed outside the electrical room.

Both Chiller 1 and Chiller 4 ran continuously during the 3-day monitoring period.

The chilled water pumps serving each operating chiller are constant-speed. Modulation of the amount of cooling provided by each cooling coil is achieved by 3-way valves.

The main chilled water plant has two 15-hp chilled water pumps. Only one of them (Pump 2) operated during the 3-day study; it ran continuously. The chilled water pump motors are constant speed.

There are two 25-hp condenser water pumps. Only one of them (Pump 2) ran during the 3-day study. The pump motors are equipped with variable-speed drives.

Figure 9. Chiller 1

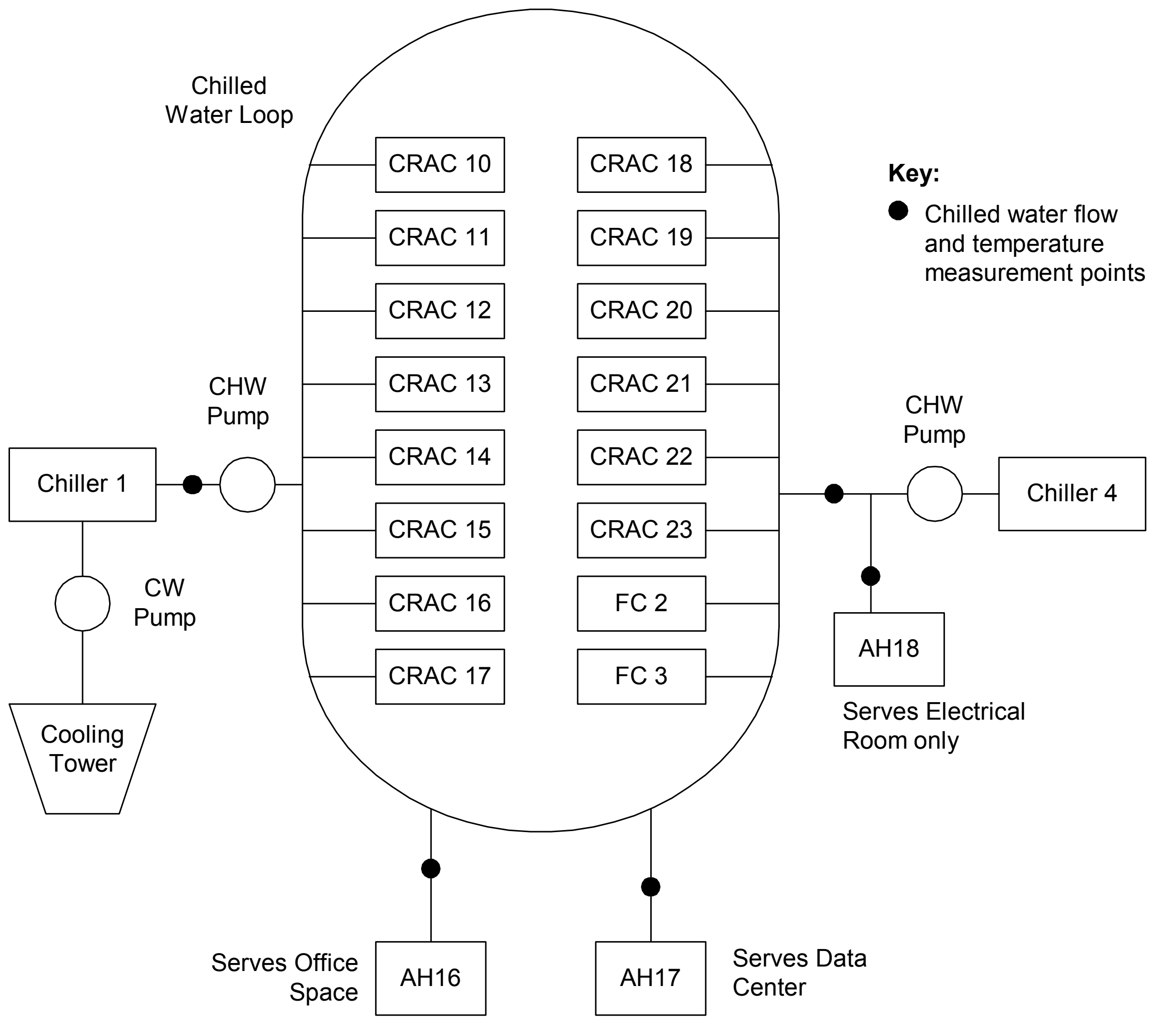
Figure 10. Chiller 4

The main plant has a pair of cooling towers. Each cooling tower has one variable-speed fan motor. The condenser water circulates through both towers simultaneously whenever the condenser pump operates, regardless if the fans are running or not. The fan in Cooling Tower 1 ran continuously during the 3-day study; Cooling Tower 2 did not. The main plant is not equipped to do water-side economizing.

The Chiller 4 plant is air cooled, so it does not have condenser pumps or cooling towers. It has two 10 hp chilled water pumps, also numbered 1 and 2. Only Pump 2 operated during the 3-day study. It ran continuously. The pump motors are constant-speed.

The entire HVAC system is controlled and monitored by a Barber Coleman Network 8000 system.

Figure 11. Simplified Schematic of Chilled Water System



Electric power consumption, chilled water flow, and chilled water temperatures[6] were measured in both chiller plants over two days. Minute-by-minute chiller cooling loads were obtained by multiplying the chilled water flow rate by the chilled water supply and return temperature differential, and by the appropriate conversion factors. The average cooling load is the average of all the 1-minute loads. See Table 6. The outdoor air temperature varied between 40°F and 60°F during this period, and the outdoor relative humidity varied between 60% and 100%[7]. Appendix A contains graphs of the recorded data.

Table 6. Chilled Water Plant Electrical and Load Measurements

Equipment	Nominal Size	Spot / Monitored	Date(s)	Average Value
Chiller 1				
Chiller 1 Power Consumption	n/a	Monitored	1/7/03 – 1/8/03	42.0 kW
Chiller 1 Cooling Load	150 tons	Monitored	1/7/03 – 1/8/03	63.9 tons
Chilled Water Pump 2	15 hp	Spot	1/7/03	8.5 kW
Condenser Water Pump 2	25 hp	Monitored	1/8/03	3.8 kW
Cooling Tower 1 Fan	n/a	Monitored	1/8/03	0.3 kW
Chiller 4				
Chiller 4 Power Consumption	n/a	Monitored	1/7/03 – 1/8/03	36.4 kW
Chiller 4 Cooling Load, Total	100 tons	Monitored	1/7/03 – 1/8/03	47.7 tons
Chilled Water Pump 2	10 hp	Spot	1/8/03	6.7 kW

During the monitored period Chiller 1 drew between 38.9 and 44.5 kW, with an average 42.0 kW. Chiller 1 delivered between 53.5 and 70.1 tons of cooling, with an average of 63.9 tons.

A spot measurement of Chilled Water Pump 2 yielded 8.5 kW.

[6] These were measured using a Summit Technology PowerSight PS3000 for electric loads, a Controlotron 1010 ultrasonic flow meter for chilled water flow, and a Pace Scientific XR440 Pocket Logger equipped with thermistors to measure the chilled water supply and return temperatures. 1-minute samples.
[7] Measured with a Pace Scientific XR440 Pocket Logger equipped with a TRH-100 sensor. 1-minute samples. Instrument installed outside building, in shade, near Chiller 4.

Condenser Water Pump 2 is outfitted with a variable speed drive. A variable speed condenser water pump is a good energy saving strategy if the pump serves multiple chillers, or serves a single chiller that has a varying load. Care must be taken to not let the condenser water flow drop below the chiller manufacturer's recommended minimum. The power consumption of Pump 2 was monitored for 3.5 hours on 1/8/03; it averaged 3.8 kW. The data shows a pronounced 1-hour cycle, between approximately 3 kW and 4.5 kW. A chart is included in Appendix A. Facility staff indicated that the variable speed drive uses the pressure drop across the chiller condenser as a control signal, but did not have an immediate explanation for the observed cycling. It appears the control scheme would benefit from a re-examination.

The fan in Cooling Tower 1 drew a relatively constant 0.3 kW during 3 hours of monitoring.

The power draw of Chiller 4 cycled up and down in a regular pattern as it operated. This is typical for reciprocating chillers, as the compressors stage on and off. The minimum value seen during the period of measurement was 26.4 kW, the maximum was 48.4 kW, and the average was 36.4 kW.

A spot measurement of Pump 2 on the Chiller 4 plant yielded 6.7 kW.

AIR HANDLERS

The cooling coils in air handlers AH16, AH17, and AH18 all use chilled water from the chilled water distribution loop. AH16 serves office space which is not part of the data center. AH17 serves only the data center. AH18 serves only the electrical room.

AH16 and AH17 both draw air from a common air-side economizer.

AH17 and AH18 are equipped with Bell & Gossett circuit setters. These devices are basically manually adjustable valves that have an indicator wheel to show valve position, and two access ports for measuring the pressure drop across the valve. Given the valve size, indicator position, and pressure reading, the flow rate can be found in the Bell & Gossett tables.

AH16 is outfitted with a non-adjustable orifice plate that serves the same flow-limiting purpose as the circuit setters. It is equipped with access ports for reading pressure, but has no other identifying information on it. No specification is found in the available mechanical drawings.

The tons of cooling provided by a given cooling coil are obtained by multiplying the chilled water flow rate by the chilled water supply and return temperature differential. Table 7 shows the results.

Table 7. Makeup Air Handler Measurements

Handler	Parameter	Spot / Monitored	Date(s)	Average Value
AH16	Power Consumption	not measured	n/a	n/a
	Cooling Coil Load	Monitored	1/6/03 – 1/8/03	0.0 tons
AH17	Power Consumption	Spot	1/7/03	0.57 kW
	Cooling Coil Load	Monitored CHW Temps; Spot CHW Flow	1/6/03 – 1/8/03	0.0 tons
	Cooling Provided to Data Center	Spot	1/8/03	1.2 tons
AH18	Power Consumption	Spot	1/7/03	4.98 kW
	Cooling Coil Load	Spot	1/6/03	37.5 tons

The power consumption of AH16 was not measured because the office space is not part of this study. The tonnage of AH16 is required so it can be subtracted from the total tons to get the CRAC tons. The measured pressure drop across AH16's orifice plate was very small for the entire monitored period. A chart of the pressure readings is included in Appendix A. For the purposes of this study, the cooling coil load of AH16 is treated as zero. Note that the office space still received cooling via the air-side economizer.

A spot measurement of the pressure drop across the circuit setter[8] on AH17 yielded a result of 15 gpm of chilled water flow. However, the difference in the monitored supply and return chilled water temperatures showed essentially a zero temperature difference. A chart is included in Appendix A. Like AH16, AH17 used outside air to provide cooling during the monitored period. The cooling delivered to the data center was calculated from the air flow and temperature readings at the supply air diffusers in the data center. See Appendix C for details.

A spot measurement of the pressure drop across the circuit setter on AH18 yielded a result of 78 gpm of chilled water flow. A spot measurement of the chilled water supply and return temperatures gave a differential of 11.55°F. The resulting cooling coil load is 37.5 tons.

[8] Spot pressure measurements were made with an Alnor HM650 hydronic manometer.

CRAC UNITS

The data center is cooled primarily by twelve floor-mounted Computer Room Air Conditioning (CRAC) units. In addition, there are four fan coil units mounted in the interstitial space above the ceiling tiles. See Figure 2 and Table 1.

All sixteen units use chilled water, have constant-speed fans, and serve only the data center. All units except FC-2 and FC-3 are equipped with electric humidifying units. Electric reheat is used during dehumidification. All sixteen units were running during the period of measurement.

The outside dry bulb air temperature varied between 40 °F and 60 °F during this time, and the outside air relative humidity varied between 60% and 100%. A chart of outside air conditions is included in Appendix A.

Table 8. CRAC Unit Settings

Label	Temperature (°F)		Relative Humidity (%)	
	Setpoint	Tolerance	Setpoint	Tolerance
CRAC-10	70	3	45	3
CRAC-11	70	3	40	3
CRAC-14	70	3	40	3
CRAC-15	70	3	45	3
CRAC-16	70	3	50	3
CRAC-17	70	3	50	3
CRAC-18	70	10	40	15
CRAC-19	70	10	40	15
CRAC-13	70	3	50	3
CRAC-20	70	3	45	3
CRAC-21	70	3	45	3
CRAC-22	69	3	48	3
CRAC-12	70	3	45	5
CRAC-23	70	2	50	5
FC-2	n/a	n/a	n/a	n/a
FC-3	n/a	n/a	n/a	n/a

The measurement team did not measure temperature and humidity in the data center with independent instruments. Ambient conditions as reported by the digital displays on the CRAC units are shown in Table 10.

Figure 12. CRAC 14

The actual cooling tons delivered by each individual CRAC unit was not measured.

Spot measurements were made of the power consumption of all the CRAC units; see Table 9.

Table 9. CRAC Power Consumption Measurements[9]

Label	Nominal Size (tons)	Date & Time	Power Consumption (kW)	Power Factor
CRAC-10	20	1/7/03 12:28	13.72	0.87
CRAC-11	20	1/7/03 10:47	4.81	--
CRAC-14	20	1/7/03 10:56	32.30	0.99
CRAC-15	25	1/7/03 10:59	14.35	0.96
CRAC-16	25	1/7/03 12:25	4.76	0.72
CRAC-17	25	1/7/03 12:14	4.54	0.72
CRAC-18	5	1/8/03 17:30	1.23	0.89
CRAC-19	5	1/8/03 17:37	1.25	0.99
CRAC-13	20	1/7/03 12:22	4.66	0.74
CRAC-20	5	1/7/03 12:17	11.86	0.93
CRAC-21	5	1/7/03 11:03	9.40	0.86
CRAC-22	20	1/7/03 11:10	10.26	0.86
CRAC-12	10	1/7/03 10:52	18.71	0.99
CRAC-23	10	1/7/03 12:20	4.88	0.91
FC-2 & FC-3	?	1/8/03 17:49	1.68	0.61
Total	>215	--	138.4	--

FC-2 and FC-3 are on the same circuit. The units are staged; FC-2 comes on first, and FC-3 comes on only if needed.

The total electric power consumption of the CRAC units was measured as 138.4 kW. This is essentially the sum of the electric power draw of the fan motor in each unit, plus any humidifier or reheat power. The power levels vary significantly from one unit to the other. Table 10 points to an explanation of why this is so.

[9] All spot measurements were made with a Powersight model PS3000 and clamp-on, 1000-amp current transducers.

Table 10. CRAC Display Panel Readings[10]

Label	CW Valve Position (%)	Ambient Temp. (°F)	Ambient Relative Humidity (%)	Heating (%)	De-humid. (%)	Humid. (%)	Time
CRAC-10	0	68	48	33	38	0	10:11
CRAC-11	0	69	48	33	100	0	10:13
CRAC-14	100	66	42	66	100	--	10:16
CRAC-15	23	70	39	0	--	100	10:15
CRAC-16	42	70	46	0	off	--	10:06
CRAC-17	34	70	47	0	off	--	10:07
CRAC-18	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CRAC-19	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CRAC-13	38	69	47	0	off	off	10:20
CRAC-20	0	67	43	50	off	--	11:34
CRAC-21	0	69	44	0	off	--	11:38
CRAC-22	44	69	39	0	--	100	11:37
CRAC-12	100	69	46	66	100	--	10:49
CRAC-23	7	69	45	0	--	100	10:50
FC-2	n/a	n/a	n/a	n/a	n/a	n/a	n/a
FC-3	n/a	n/a	n/a	n/a	n/a	n/a	n/a

In the Main Computer Room, CRAC units 11 and 14 are in 100% dehumidifying mode, and CRAC 15 is in 100% humidifying mode. Likewise, in the Tape Room, CRAC units 12 and 23 are working at cross-purposes. Table 8 offers additional evidence. In the Main Computer Room, the relative humidity tolerance for each CRAC unit is a tight +/- 3%, but CRAC units 11 and 14 have a setpoint of 40% RH, and CRAC units 16 and 17 are set for 50% RH. As would be expected, CRAC units 11 and 14 are in dehumidifying mode.

In general, it appears that the units in dehumidifying mode draw about 2 kW per nameplate ton, those in humidifying mode draw about 0.5 kW per nameplate ton, and those that are neither humidifying or dehumidifying draw about 0.2 kW per nameplate ton. CRAC units 11, 20, and 21 don't follow this pattern, but that may be due to the fact that the power levels and the digital displays were read at different times. The CRAC unit humidifying and dehumidifying functions are likely cycling on and off.

This situation bears further investigation. If the CRAC units are indeed fighting each other over humidity control, rectifying the problem will save significant energy.

[10] All spot measurements were made with a Powersight model PS3000 and clamp-on, 1000-amp current transducers. All readings taken on 1/8/03.

Finally, the investigation team performed airflow efficiency measurements on CRAC units 13 and 16. These units were selected because neither of them was in humidifying or dehumidifying mode. The power consumption for each is essentially due to the fan motor.

Table 11. CRAC 16 Air Flow Efficiency

Grid	Date & Time	Average Velocity	Average Flow Rate	Notes
		fpm	cfm	
1	1/8/03 12:00	598	1860	17" x 30" Filter (16" x 28" Effective Area)
2	1/8/03 12:00	585	1818	17" x 30" Filter (16" x 28" Effective Area)
3	1/8/03 12:00	522	1625	17" x 30" Filter (16" x 28" Effective Area)
4	1/8/03 12:00	598	1861	17" x 30" Filter (16" x 28" Effective Area)
5	1/8/03 12:00	612	1903	17" x 30" Filter (16" x 28" Effective Area)
6	1/8/03 12:00	404	530	8" x 28" Filter (7" x 27" Effective Area)
		Total cfm	9597	
		kW	4.76	From Table 9
		cfm/kW	2020	

Table 12. CRAC 13 Air Flow Efficiency

Grid	Date & Time	Average Velocity	Average Flow Rate	Notes
		fpm	cfm	
1	1/8/03 13:00	695	2161	17" x 30" Filter (16" x 28" Effective Area)
2	1/8/03 13:00	660	2052	17" x 30" Filter (16" x 28" Effective Area)
3	1/8/03 13:00	594	1849	17" x 30" Filter (16" x 28" Effective Area)
4	1/8/03 13:00	689	2144	17" x 30" Filter (16" x 28" Effective Area)
		Total cfm	8206	
		kW	4.66	From Table 9
		cfm/kW	1762	

LIGHTING

Lighting in the data center consists of T-8 fluorescent lamps with electronic ballasts. There are four lamps and two ballasts per fixture. There are no occupancy sensors. According to facility staff, the lights are on continuously. The total lighting power was estimated by counting the number of fixtures and multiplying by 32 Watts per lit lamp and 8 Watts per ballast.

Table 13. Lighting Power

	Floor Area (Sq. Ft.)	Fixture Count	No. of Lamps Not Lit	kW
Main Computer Room	6,450	87	16	12
Network Room	900	16	0	2
New Print Room	3,680	26	4	4
Old Print Room	2,260	44	3	6
Tape Room	1,580	14	0	2
Phone Room	450	n/a	n/a	n/a
Totals:	15,320	187	23	26

The lighting power density is 1.7 Watts per square foot of gross floor area. This is much higher than the typical 1.0 W/sf for office environments.

SUMMARY MEASUREMENTS AND METRICS

SUMMARY MEASUREMENTS

The data center net cooling load is determined indirectly. All of the cooling provided by Chiller 1 serves the data center. The cooling coil load of air handler AH18 is subtracted from the total tons provided by Chiller 4; the remainder serves the data center. Finally, the cooling provided by makeup air handler AH17 is included. Table 14 shows the result.

Table 14. Total Data Center Cooling Load

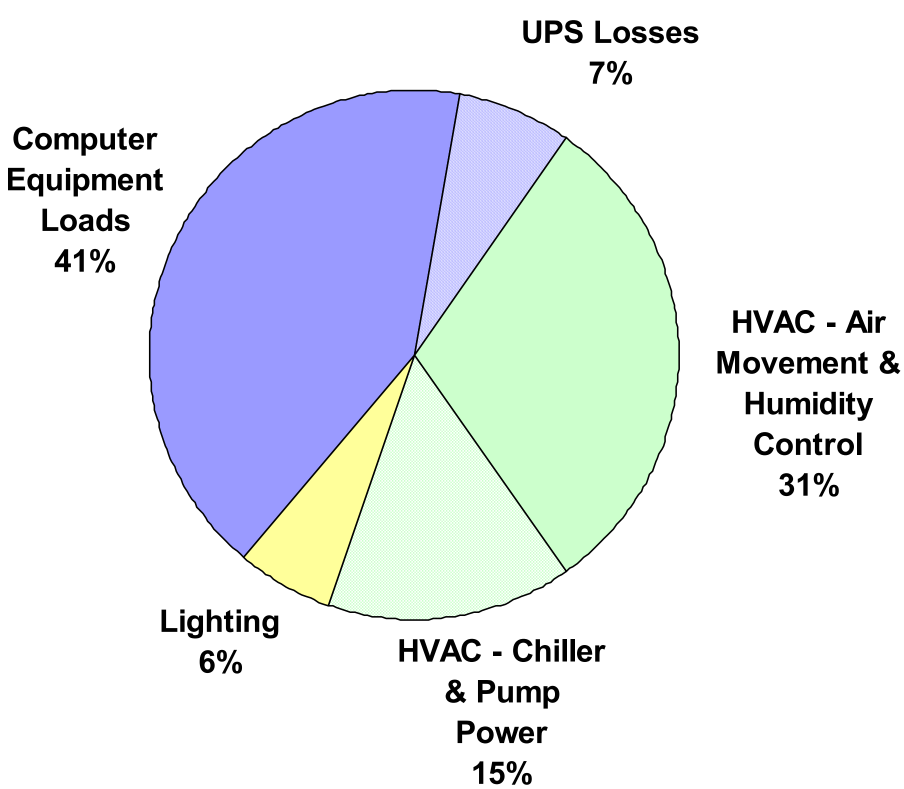
Cooling Provided By	Average Value
Chiller 1	63.9 tons
Chiller 4 (not including AH18 load)	10.2 tons
AH17	1.2 tons
Total	75.3 tons

Table 15 brings together all the electrical measurements for the data center.

Table 15. Summary of Electrical Measurements

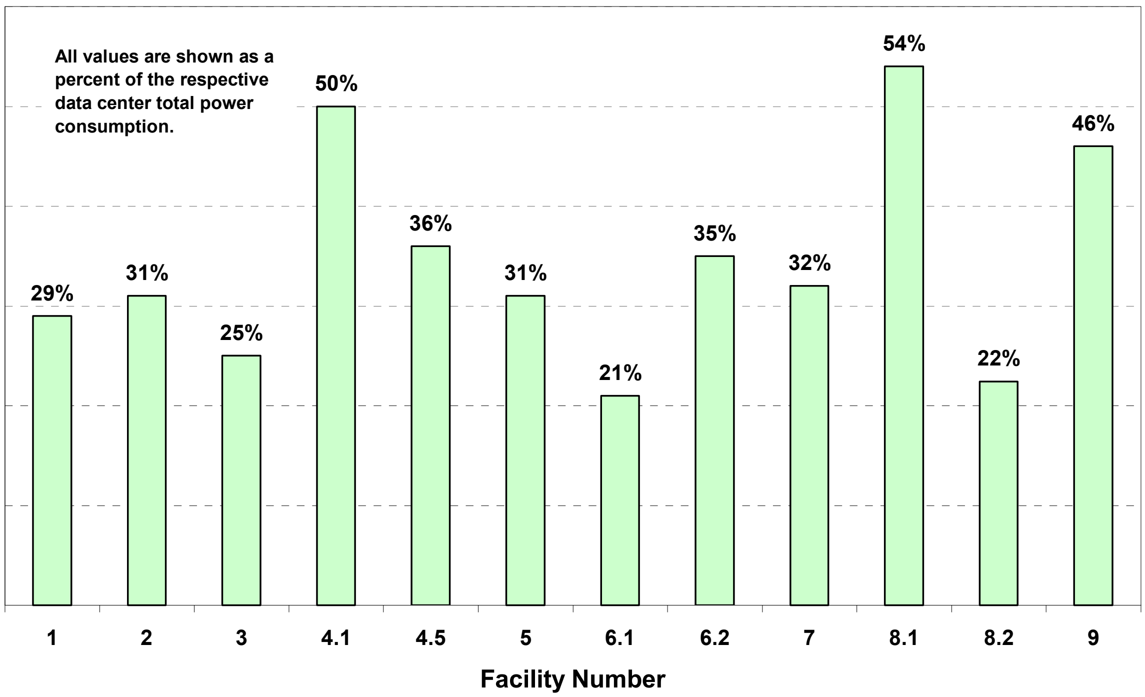
Item	Remarks	Value	Percent
Computer Equipment Loads	Total UPS output. (All data center equipment is served by PDUs; all PDUs are served by UPS system.)	190.0 kW	41%
UPS Losses	Total UPS input minus total UPS output.	30.6 kW	7%
HVAC – Air Movement & Humidity Control	Electrical energy for all CRAC and Fan Coil Units in data center, plus AH17 fan energy.	139.0 kW	31%
HVAC – Chiller & Pump Power	Power consumption of chillers, pumps, and cooling tower fan. Chiller 4 power prorated to account for AH18 load.	69.1 kW	15%
Lighting	Calculated from fixture count.	26.2 kW	6%
Total Energy Use	--	454.9 kW	100%

Figure 13. Data Center Energy Balance



The computer equipment load served by the UPS system is 41% of the data center energy usage. The energy used to cool the data center outweighs this; pumping and chiller energy accounts for 15% of the total, and air movement and humidity control amounts to 31%, for a total of 46%. See Figure 14 for a comparison to the other facilities studied as part of the Data Center Load Characterization Project. UPS losses account for 7% of the data center energy consumption, and the lights account for the remaining 6%.

Figure 14. HVAC Power Comparison



ELECTRICAL CONSUMPTION METRICS

Table 16 addresses the issue of data center load density. The most commonly used metric among mission critical facilities is the computer load density in Watts consumed per square foot (W/sf). However, even in a prototypical data center filled entirely with closely spaced racks of similar equipment, the choice of what to use as square footage is not always consistent between analysts, and can be a source of confusion.[11] In the case of Data Center Facility 9, the choice is further complicated by the fact that the various rooms that make up the data center have various kinds of equipment in them. For the purposes of this report, no breakdown of the different types of computer equipment is performed. All the types are treated alike, and termed "computer equipment".

[11] See "Data Center Power Requirements: Measurements from Silicon Valley", by Mitchell-Jackson, Koomey, Nordman, & Blazek, December 2001. It is available on the web at http://enduse.lbl.gov/Info/Data_Center_Journal_Articl2.pdf.)

Table 16. Electrical Consumption Metrics

Metric		Value	Units
Data Center Gross Area		15,300	sf
Computer Equipment Footprint		1,970	sf
Computer Load Density based on Data Center Gross Area		12.4	W/sf
Computer Load Density based on Computer Equipment Footprint		96.4	W/sf
Current Occupancy	Main Computer Room	40	%
	Network Room	70	%
	New Print Room	30	%
	Old Print Room	80	%
	Tape Room	100	%
	Phone Room	100	%
Computer Load Density based on Occupied Floor Area		23.3	W/sf
Computer Load at 100% Occupancy		428	kW

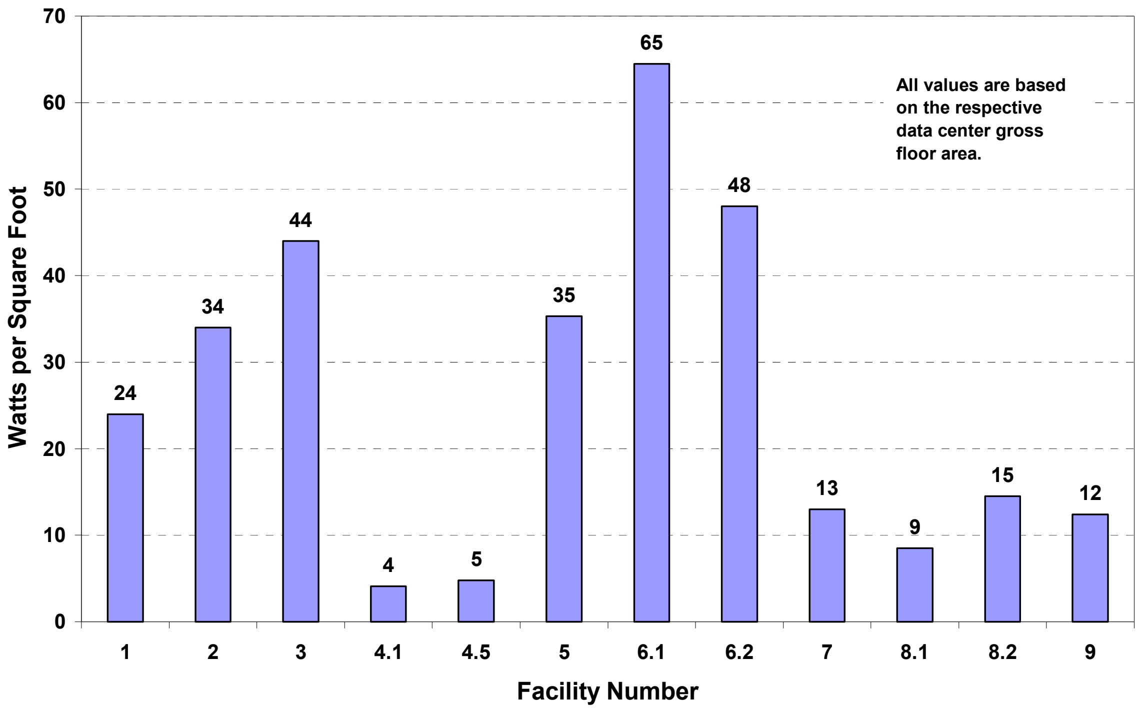
"Data Center Gross Area" is the entire floor area of the data center. Per the Uptime Institute Definitions, this gross floor space is what is typically used by facility engineers in calculating a computer load density (W/sf).[12]

"Computer Equipment Footprint" is the portion of the floor area immediately underneath the equipment. For computer load, we use the total UPS output of 190.0 kW.

The computer load density based on the gross area is 12.4 W/sf. This is well below current typical data center densities, which are in the range of 30 to 50 W/sf. For comparison with other facilities measured as part of the Data Center Load Characterization Project, see Figure 15.

[12] Users look at watts per square foot in a different way. With an entire room full of communication and computer equipment, they are not so much concerned with the power density associated with a specific footprint or floor tile, but with larger areas and perhaps even the entire room. Facilities engineers typically take the actual UPS power output consumed by computer hardware and communication equipment in the room being studied (but not including air handlers, lights, etc.) and divide it by the gross floor space in the room. The gross space of a room will typically include a lot of areas not consuming UPS power such as access aisles, white areas where no computer equipment is installed yet, and space for site infrastructure equipment like Power Distribution Units (PDU) and air handlers. The resulting gross watts per square foot (watt/ft^2-gross) or gross watts per square meter (watt/m^2-gross) will be significantly lower than the watts per footprint measured by a hardware manufacturer in a laboratory setting.

Figure 15. Computer Load Densities



The computer load density based on the computer equipment footprint is 96.4 W/sf.

Occupancy was determined by examining the electronic drawings for the data center. The computer equipment in the main computer room is clustered most closely together in the north end of the room. If the main computer room was built out such that the entire room achieved this spatial density, there would approximately 2.5 times as much equipment in the room. Thus the current occupancy is 40%.

A similar calculation for the Network Room, New Print Room and the Old Print Room yields 70%, 30%, and 80%, respectively.

The Tape Room and Phone Room are fully occupied with their respective types of equipment.

Using the current average computer load density for the entire data center and extrapolating to full occupancy yields 428 kW. This is within the 500 kVA capacity of each UPS.

HVAC EFFICIENCY METRICS

Since the packing of data centers and computer types are site specific, a more useful metric for evaluating how efficiently the data center is cooled can be represented as a ratio of cooling power to computer power.

Another metric is the “theoretical cooling load”. It is the sum of the computer, lighting, and CRAC electrical loads. All of these loads equate to heat that must be removed from the room. (Though there is a small amount of human activity, this is insignificant compared to the other loads.)

Chiller efficiency is usually presented as the ratio of chiller power at full load to the tons of cooling provided at full load, in units of kW/ton. Chilled water plant efficiency is similar, but it includes the power consumption of the cooling tower and pumps as well. HVAC system efficiency adds the power consumption of the air handlers and CRAC units.

Table 17. HVAC Efficiency Metrics

Metric	Average Value	Units
Cooling kW / Computer Load kW	1.10	--
Theoretical Cooling Load	101	tons
Cooling Provided by HVAC System	75.3	tons
Chiller 1 Efficiency	0.66	kW/ton
Chiller 4 Efficiency	0.76	kW/ton
Chilled Water Plant Efficiency	0.93	kW/ton
HVAC System Efficiency	2.81	kW/ton

The data center uses 10% more energy to provide cooling for the computers, than the computers themselves consume. This figure does not include the efficiency loss in the UPS, or the energy required to keep the UPS cool.

The theoretical load is 34% higher than the measured cooling delivered by the HVAC system. It is likely that some of heat generated in the data center is escaping through the roof and in to adjoining spaces in the facility.

The efficiency of Chiller 1 averaged 0.66 kW/ton. This is typical for an older, lightly loaded centrifugal chiller, but newer variable-speed chillers can be much more efficient. Efficiencies of 0.3 kW/ton or less are possible.

The efficiency of Chiller 4 averaged 0.76 kW/ton. This is less efficient than Chiller 1, but it is fairly good performance for an air-cooled reciprocating unit.

The chilled water plant as a whole – both chillers and their associated chilled water pumps, the condenser water pump on Chiller 1, and the cooling tower – is less efficient than either chiller by itself, but not by a huge amount. The variable speed drives on the condenser pump and the cooling tower keep the power consumption of those devices relatively low.

The overall HVAC system efficiency is 2.81 kW/ton. As shown previously in Figure 13, two-thirds of the HVAC power consumption is due to the CRAC units. This portion of the energy use can probably be reduced by addressing the humidifying/dehumidifying control issue in the data center.

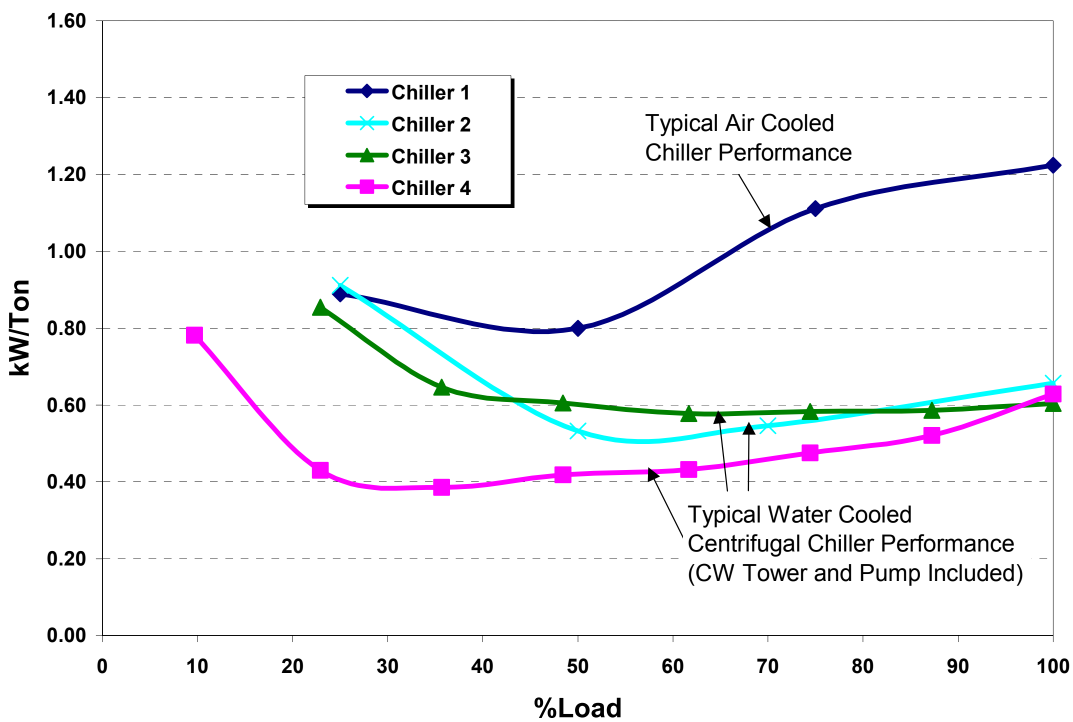
V. Energy Efficiency Recommendations

General Guidelines for Future Construction

Efficient Chilled Water System

Water cooled chillers offer enormous energy savings over air cooled chillers, particularly in dry climates, because they take advantage of evaporative cooling. Since the chiller is being cooled by lower temperature media, it can reject heat more easily, and does not have to work as hard. Though the addition of a cooling tower adds maintenance costs associated with the water treatment, we have found that the energy savings outweigh the maintenance costs. Within the options of water cooled chillers, variable speed centrifugal are the most energy efficient, because they can operate very efficiently at low loads. The graph below compares the energy performance of various chiller types.

Comparison of Typical Chiller Efficiencies over Load Range

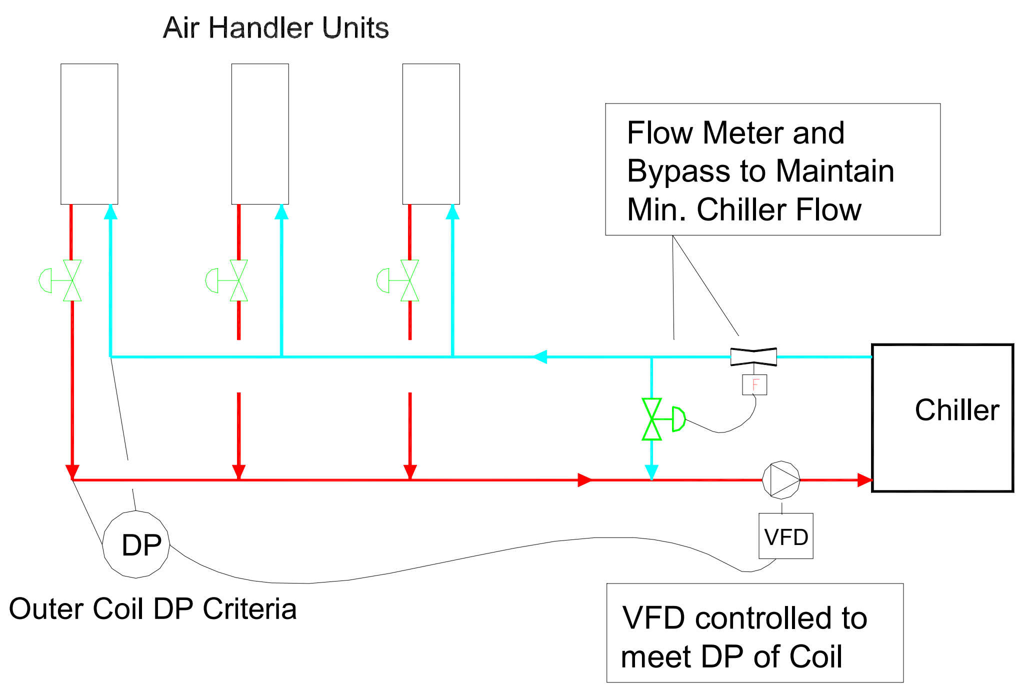


Chiller 1	250-Ton, Screw, Standard Efficiency, Air Cooled
Chiller 2	216 Ton, Screw, Water Cooled
Chiller 3	227-Ton, Centrifugal, Constant Speed, Water Cooled
Chiller 4	227-Ton, Centrifugal, Variable Speed, Water Cooled

Though there are efficient air cooled chillers, the larger size of water cooled chillers has resulted in more care given to efficiency and life cycle costs compared to air cooled chillers.

The selection of the auxiliary equipment, including the cooling tower, pumps, and pumping strategy should also be considered carefully. For example, variable speed fans on cooling towers allow for optimized cooling tower control. Premium efficiency motors and high efficiency pumps are recommended, and variable speed pumping is a ripe opportunity for pump savings. Variable pumping strategies can be achieved in a primary/secondary scheme, where the primary pumps operate at constant speed and directly feed water to the chiller, and the secondary pumps are variable speed and serve the air handling units. A more energy efficient scheme is primary-only variable speed pumping strategy. Pumping savings are based on the cube law: pump power is reduced by the cube of the reduction in pump speed, which is directly proportional to the amount of fluid pumped.

A primary only variable pumping strategy must include a bypass valve that ensures minimum flow to the chiller, and the use of two-way valves at the air handling units in order to achieve lower pumping speeds. The control speed of the bypass valve should also meet the chiller manufacturers recommendations of allowable turndown, such that optimum chiller efficiency is achieved.[13] The diagram below describes the primary-only variable speed pumping strategy.



[13] This basically means that the flow through the chiller should be varied slow enough such that the chiller is able to reach a quasi-steady state condition and able to perform to its maximum efficiency.

Air Management

The standard practice of cooling data centers employs an underfloor system fed by CRAC units. There are a number of potential problems with such systems: an underfloor system works on the basis of thermal stratification. This means that as the cool air is fed from the underfloor, it absorbs energy from the space, warming up as a result, and rises. In order to take advantage of thermal stratification, the return air must be collected at the ceiling level. CRAC units often have low return air grills, and are therefore, simply recirculating cool or moderately warmed air. Furthermore, they are often located along the perimeter of the building, and not dispersed throughout the floor area, where they can more effectively treat warm air. One alternative is to install transfer grills from the ceiling to the return grill. Another common problem with underfloor supply is that the underfloor becomes congested with cabling, increasing the resistance to air flow. This results in an increase in fan energy use. A generous underfloor depth is essential for effective air distribution (we have seen 3 feet in one facility).

An alternative to underfloor air distribution is high velocity overhead supply, combined with ceiling height return. A central air handling system can be a very efficient air distribution unit. Design considerations include using VFDs on the fans, low pressure drop filters, and coils. An additional advantage of a central air handling system is that it can be specified with an economizer function. With the favorable climate in the Bay Area, economizing can reduce the cooling load for a majority of the hours of the year.

Another common problem identified with CRAC units is that they are often fighting each other in order to maintain a constant humidity setpoint. Not only is a constant humidity setpoint unnecessary for preventing static electricity (the lower limit is more important), but it uses extra energy. A central air handling unit has a better ability to control overall humidity than distributed CRAC units.

Air Management – Rack Configuration

Another factor that influences cooling in data centers is the server rack configuration. It is more logical for the aisles to be arranged such that servers' backs are facing each other, and servers' fronts are facing each other. This way, cool air is draw in through the front, and hot air blown out the back. The Uptime Institute has published documents describing this method for air management.[14]

Commissioning of New Systems and Optimized Control Strategies

Many times the predicted energy savings of new and retrofit projects are not fully realized. Often, this is due to poor and/or incomplete implementation of the energy efficiency recommendations. Commissioning is the process of ensuring that the building systems perform as they were intended to by the design. Effective commissioning actually begins at the design stage, such that the design strategy is critically reviewed. Either the design engineer can serve as the commissioning agent, or a third party commissioning agent can be hired. Commissioning differentiates from standard start-up

[14] http://www.upsite.com/TUIpages/whitepapers/tuiaisles.html

testing in that it ensures systems function well relative to each other. In other words, it employs a systems approach.

Many of the problems identified in building systems are often associated with controls. A good controls scheme begins at the design well. In our experience, an effective controls design includes 1) a detailed points list, with accuracy levels, and sensor types, and 2) a detailed sequence of operations. Both of these components are essential for successfully implementing the recommended high efficiency chilled water system described above. Though commissioning is relatively new to the industry, various organizations have developed standards and guidelines. Such guidelines are available through organizations like the Portland Energy Conservation Inc., at www.peci.org, or ASHRAE, Guideline 1-1996.

Lighting Controls

Lighting controls such as occupancy sensors may be appropriate for areas that are infrequently or irregularly occupied. If 24-hour lighting is desired for security reasons, scarce lighting can be provided at all hours, with additional lighting for occupied periods.

Specific Recommendations

The chillers studied in this report are due to be removed soon, so no specific recommendations are provided for them.

Revisit Humidity Control Strategy

The CRAC units are programmed with humidity setpoints that vary from 40% to 50% RH, but most of the units are also programmed with relatively tight tolerances (+/- 3% RH). Observations indicate the CRAC units are working against each other as they attempt to meet their respective humidity setpoints. This consumes a significant amount of energy.

Humidity control is an important issue in the print rooms, as paper forms will tear or jam in the printers if the relative humidity is out of range. Humidity may also be an issue with the magnetic data storage tapes. If the remaining computer equipment can tolerate a wider range of humidity, though, relaxing the humidity standard will help the CRAC units stop competing with each other. Additionally, revisit the humidity setpoints. It is probably not necessary to have some CRAC units set for 40% RH and others in the same room set for 50% RH.

Run Fewer CRAC Units

The nominal cooling capacity of all the CRAC units combined is more than 215 tons. Yet, during the monitoring period, the data center called for an average of only 74 tons. All the CRAC units ran constantly during the monitored period, and all of them have constant-speed fans. If it is possible to turn off some CRAC units without creating “hot spots", then it will save the fan energy. The CRAC units that continue to operate will increase their use of chilled water to meet the total cooling demand .

Rearrange Perforated Floor Tiles for More Effective Cooling

Some of the floor tiles in the data center are perforated, to allow the cooling air to rise from the space under the floor. The investigation team noticed that many of the perforated tiles could be rearranged to more efficiently cool the computer equipment. In particular, perforated tiles should be placed in front of server racks, not behind. The cooling fans inside the servers typically draw air from the front of the rack and eject it out the back. Directing the cooling air that is coming from the floor to rise in front of the rack will provide the optimum cooling effect.

Consider Using Outside Air to Cool the Data Center

Air handler AH17 provides ventilation air to the data center through three ceiling diffusers. This air handler is capable of using outside air when the outside air is cool enough, thereby avoiding the need for the chilled water plant to provide chilled water for cooling. This concept can be employed for active cooling, not just ventilation. The outside air in Sacramento is cool and dry enough through much of the year, to allow using it directly for cooling. This would require a new air handler and ductwork to serve the data center, so a cost-benefit analysis would be called for as a first step.

Examine UPS Management Strategies

Each UPS system is large enough to carry the data center load by itself. Running one UPS at a higher load factor will yield better efficiency. However, the battery bank in each system will not be maintained properly if the respective system is not active. Perhaps it would be possible to alternate the two UPS systems in a lead/lag arrangement, one on and one off, switching them frequently enough that the batteries are not negatively impacted?

Reduce Lighting

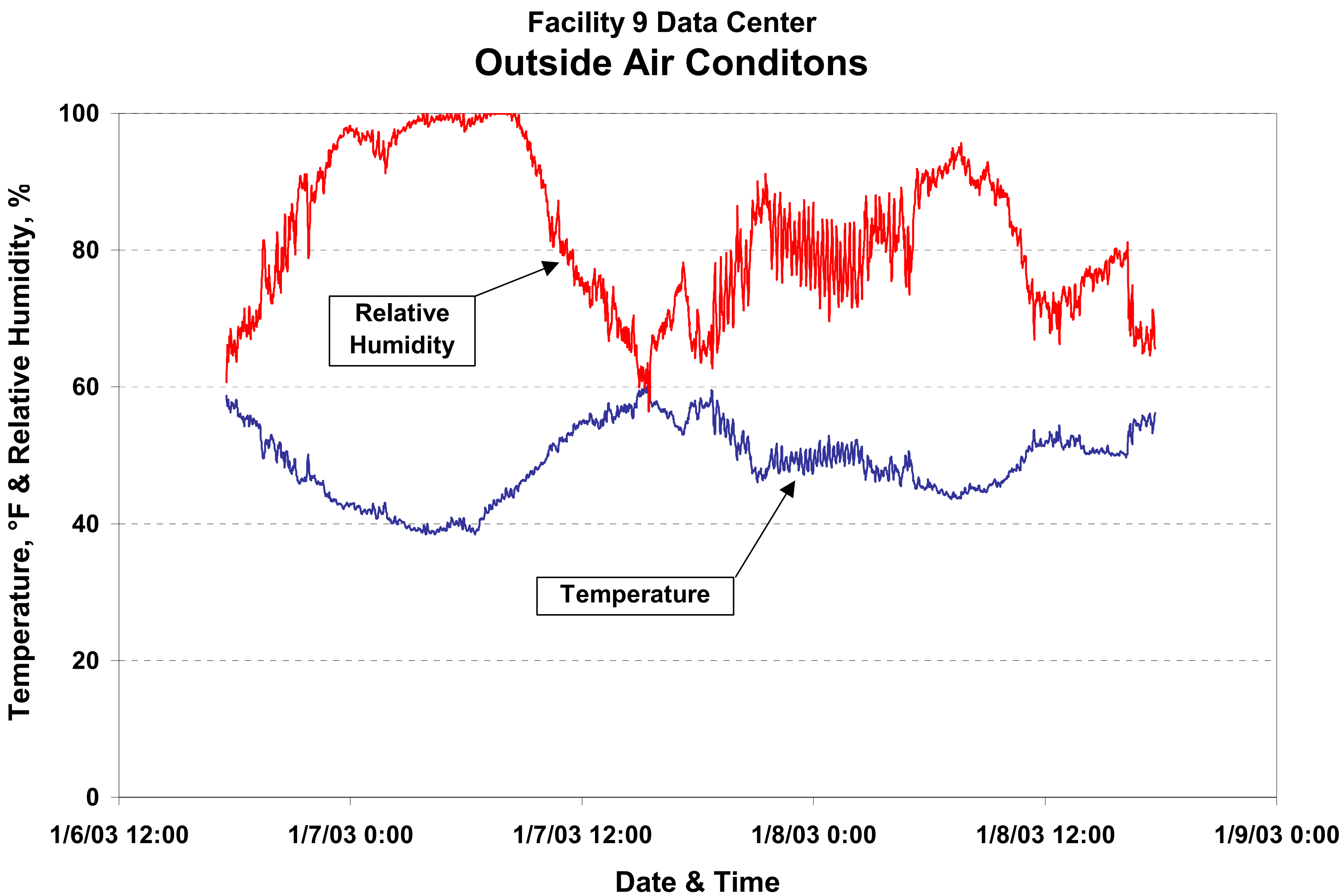
The data center is 15,300 square feet, and uses a constant 26 kW of lighting energy. If electricity costs $0.10/kWh, this represents some $23,000 per year. The lighting energy density works out to 1.7 W/sf, which is much higher than the 1.0 W/sf found in a typical office environment. In addition, some of the rooms are occupied intermittently.

Consider the following measures:

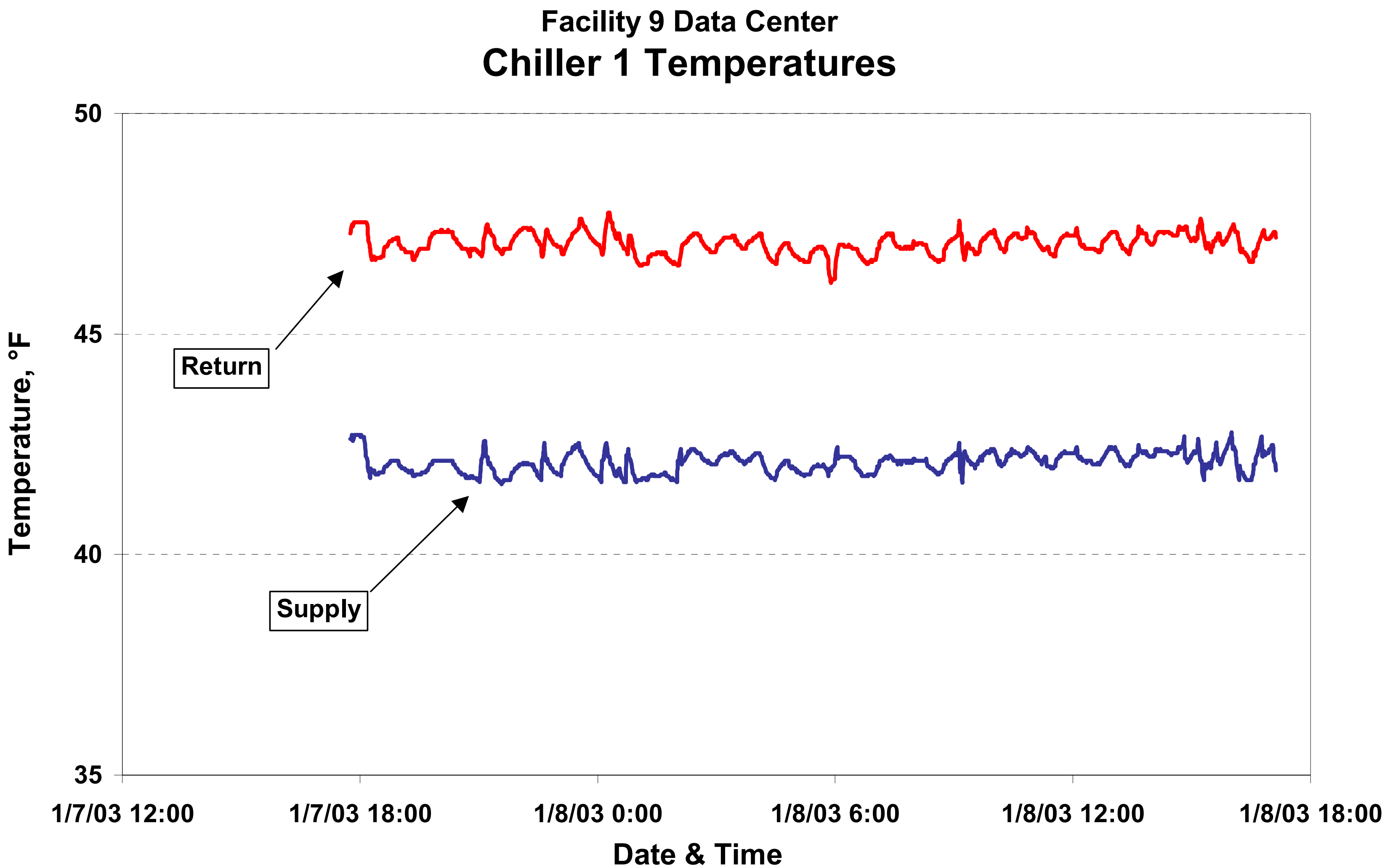
a) Install occupancy sensors to turn off most or all of the lights when the rooms are unoccupied.
b) Add task lighting in appropriate areas, and disable a portion of the overhead lights.

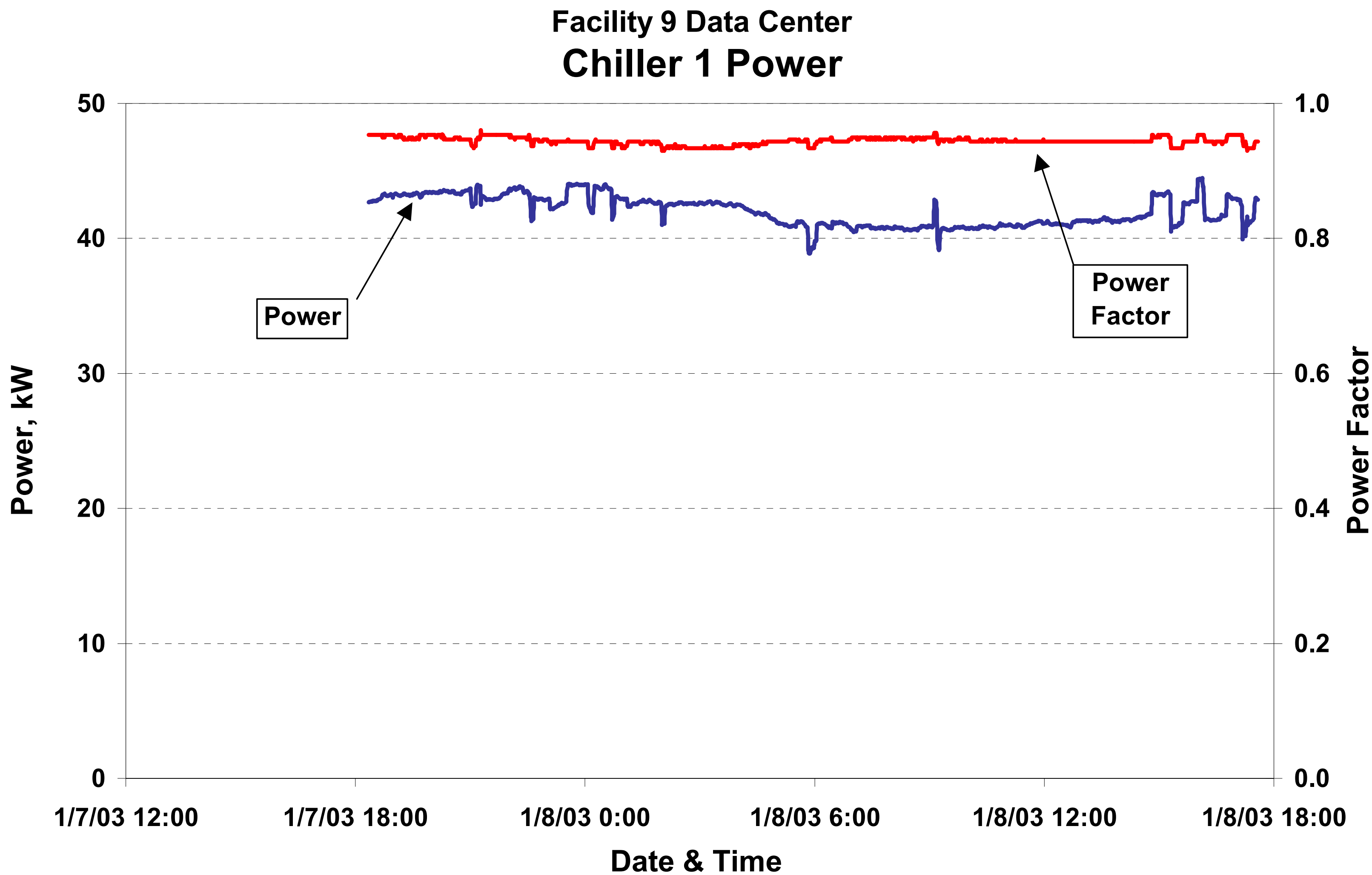
Appendix A

Charts of Measured Data



Facility 9 Data Center
Outside Air Conditons
Temperature, °F & Relative Humidity, %
100
80
60
40
20
0
Relative Humidity
Temperature
1/6/03 12:00
1/7/03 0:00
1/7/03 12:00
1/8/03 0:00
1/8/03 12:00
1/9/03 0:00
Date & Time


Facility 9 Data Center
Chiller 1 Temperatures
50
45
40
35
Temperature, °F
Return
Supply
1/7/03 12:00
1/7/03 18:00
1/8/03 0:00
1/8/03 6:00
1/8/03 12:00
1/8/03 18:00
Date & Time


Facility 9 Data Center
Chiller 1 Power
Power, kW
Power Factor
Power
Power
Factor
50
40
30
20
10
0
1.0
0.8
0.6
0.4
0.2
0.0
1/7/03 12:00
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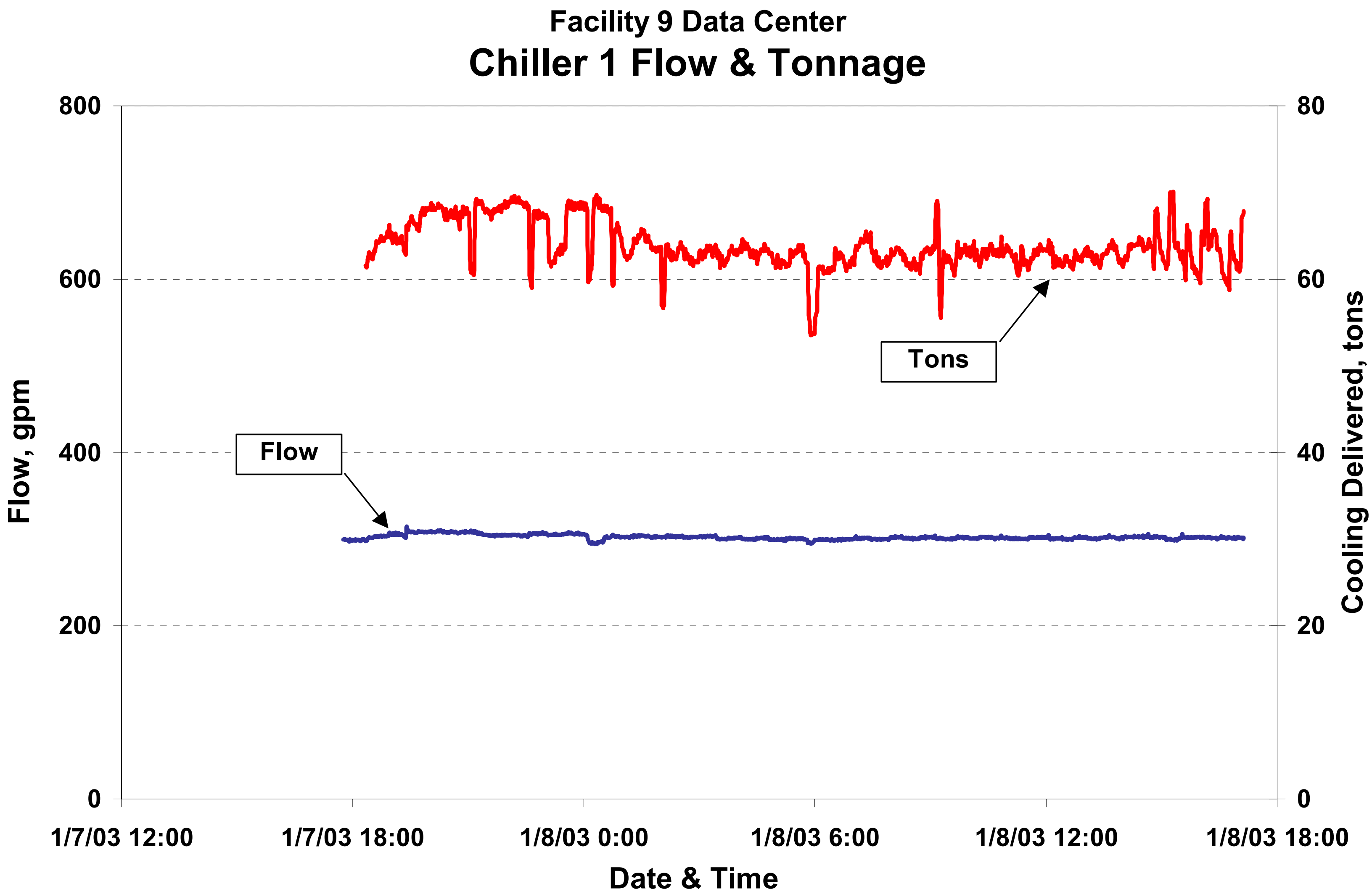
1/8/03 0:00
1/8/03 6:00
1/8/03 12:00
1/8/03 18:00
Date & Time


Facility 9 Data Center
Chiller 1 Flow & Tonnage
800
600
400
200
0
80
60
40
20
0
Flow, gpm
Cooling Delivered, tons
Tons
Flow
1/7/03 12:00
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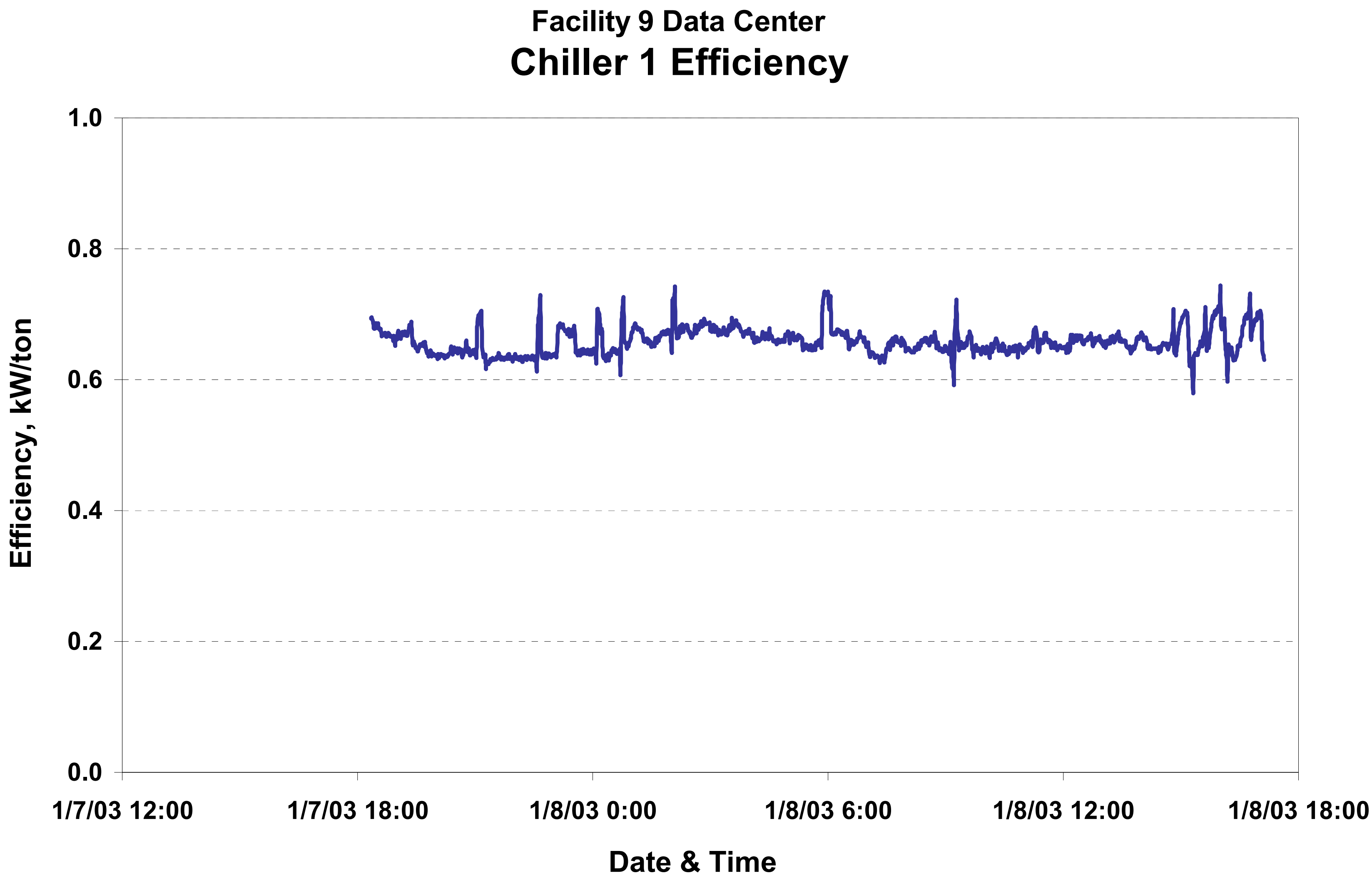
1/8/03 18:00
Date & Time


Facility 9 Data Center
Chiller 1 Efficiency
Efficiency, kW/ton
1.0
0.8
0.6
0.4
0.2
0.0
1/7/03 12:00
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1/8/03 0:00
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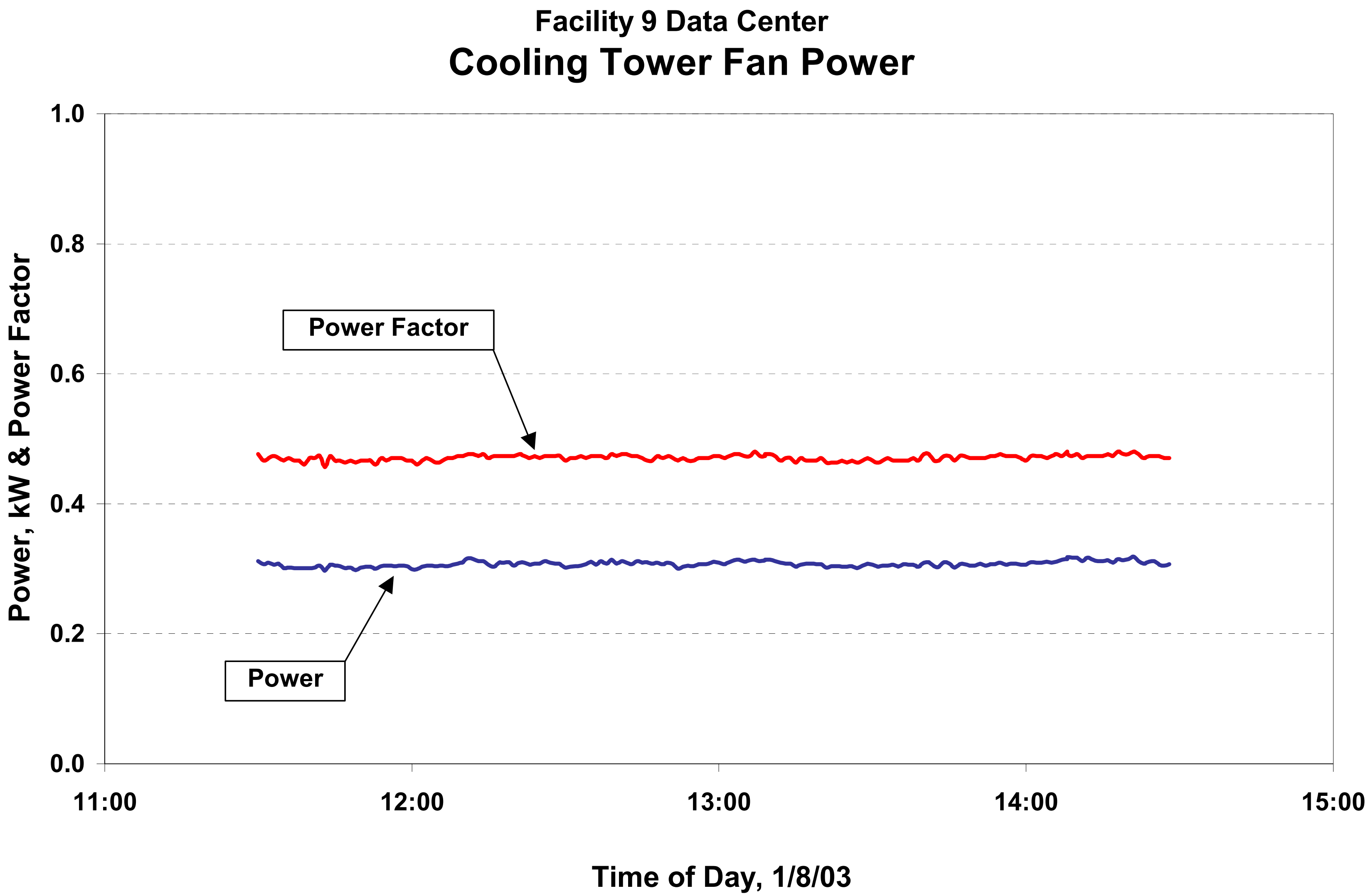
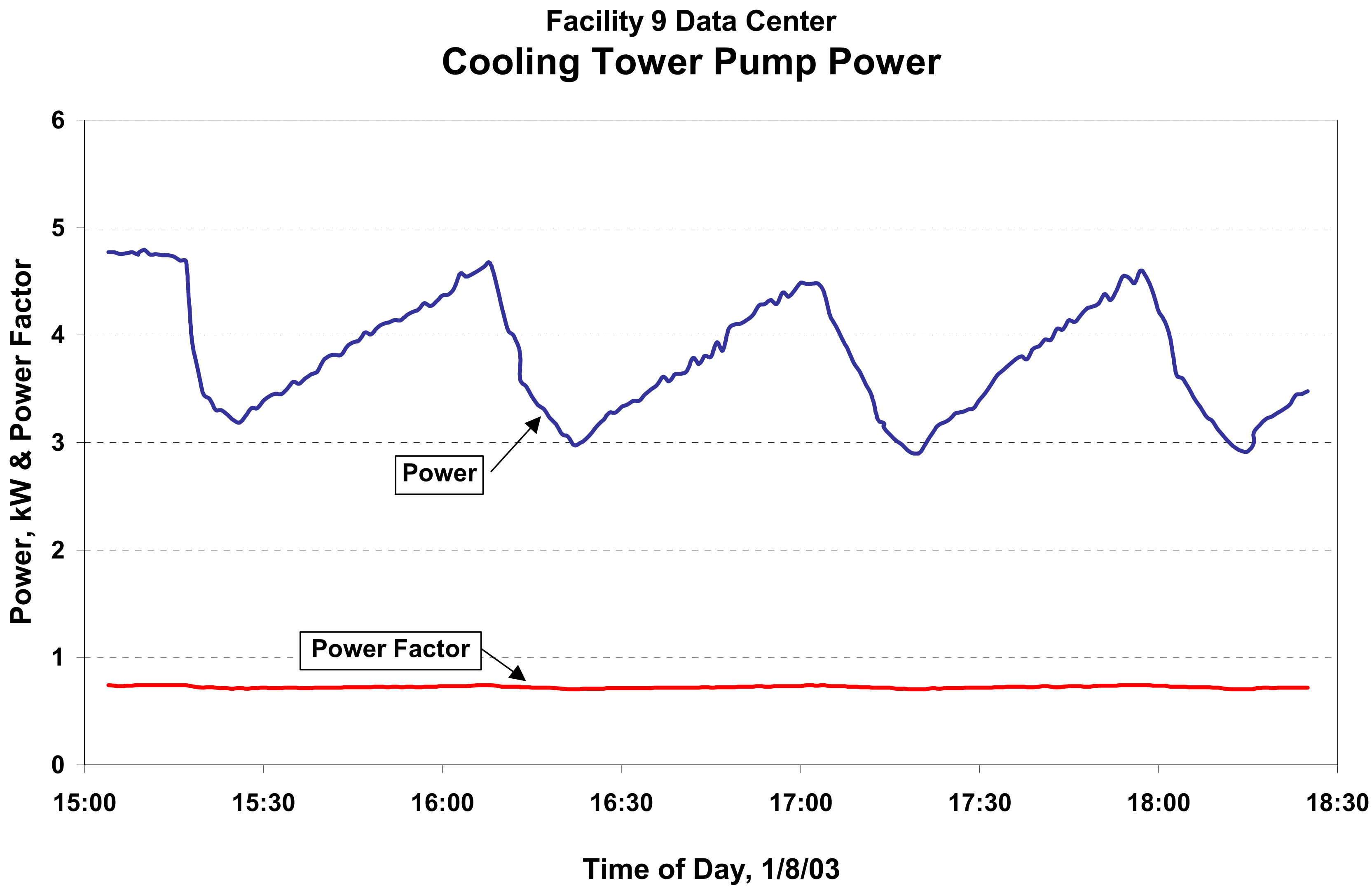
1/8/03 12:00
1/8/03 18:00
Date & Time


Facility 9 Data Center
Cooling Tower Fan Power
1.0
0.8
0.6
0.4
0.2
0.0
Power, kW & Power Factor
Power Factor
Power
11:00
12:00
13:00
14:00
15:00
Time of Day, 1/8/03


Facility 9 Data Center
Cooling Tower Pump Power
Power, kW & Power Factor
6
5
4
3
2
1
0
Power
Power Factor
15:00
15:30
16:00
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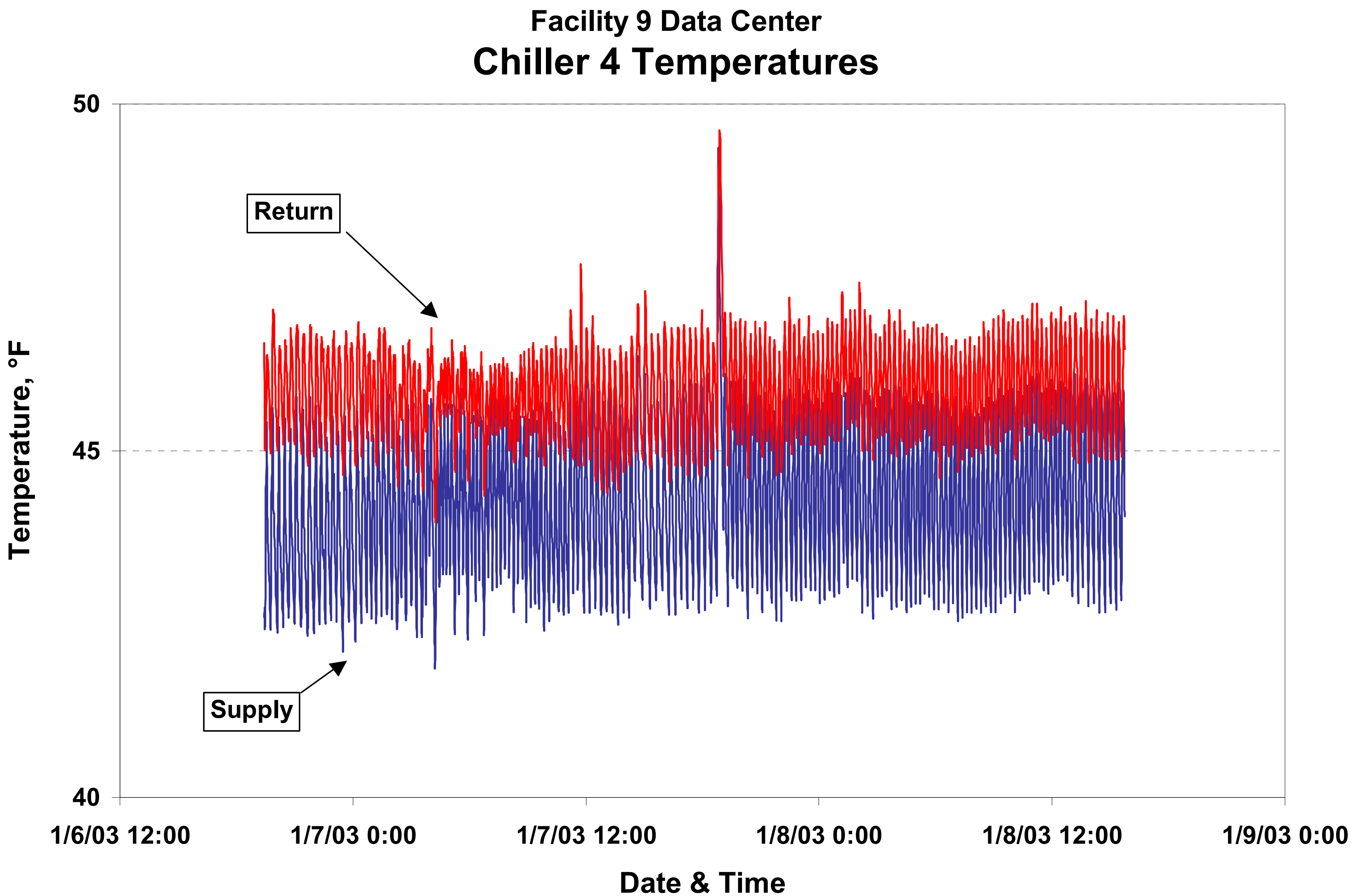
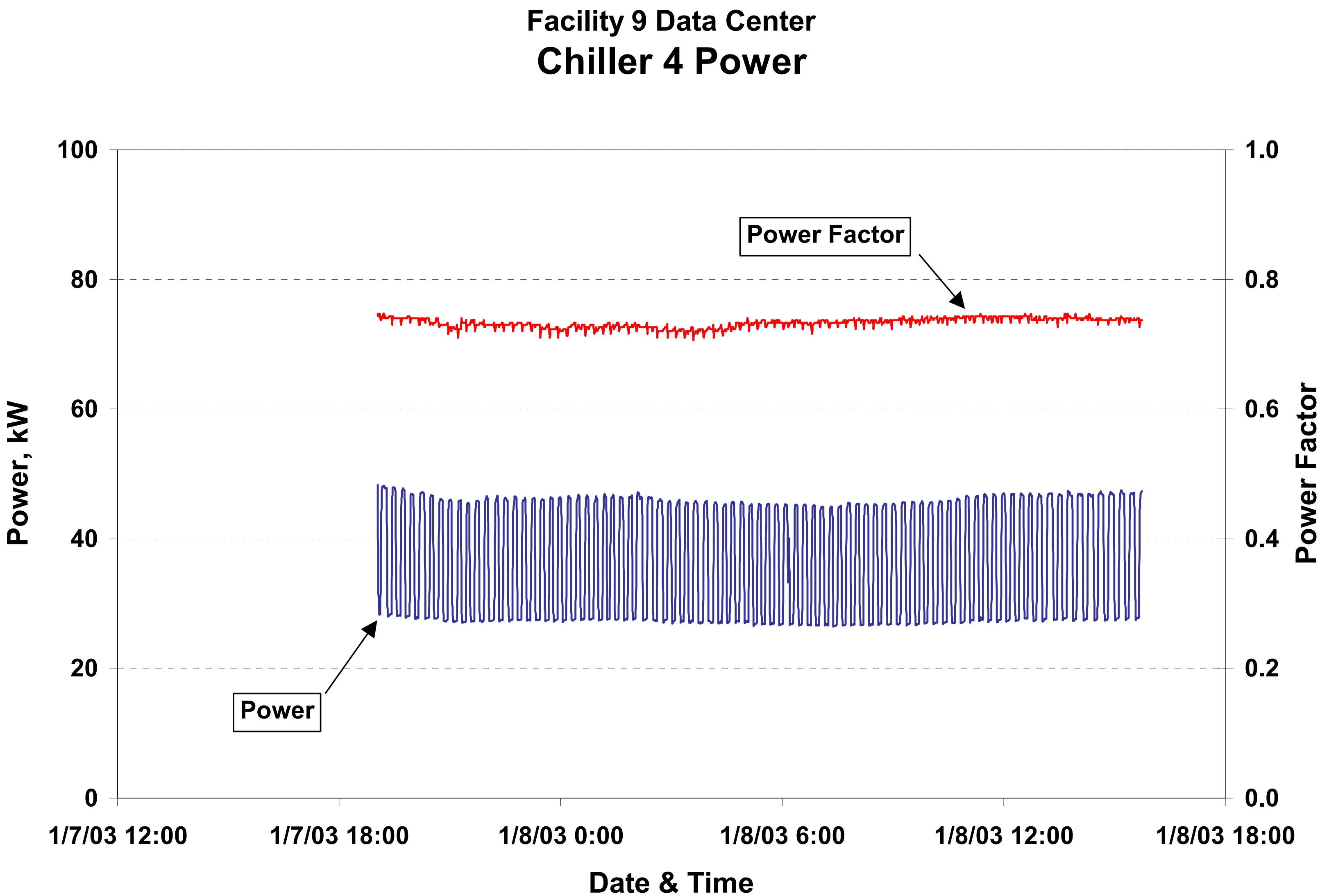
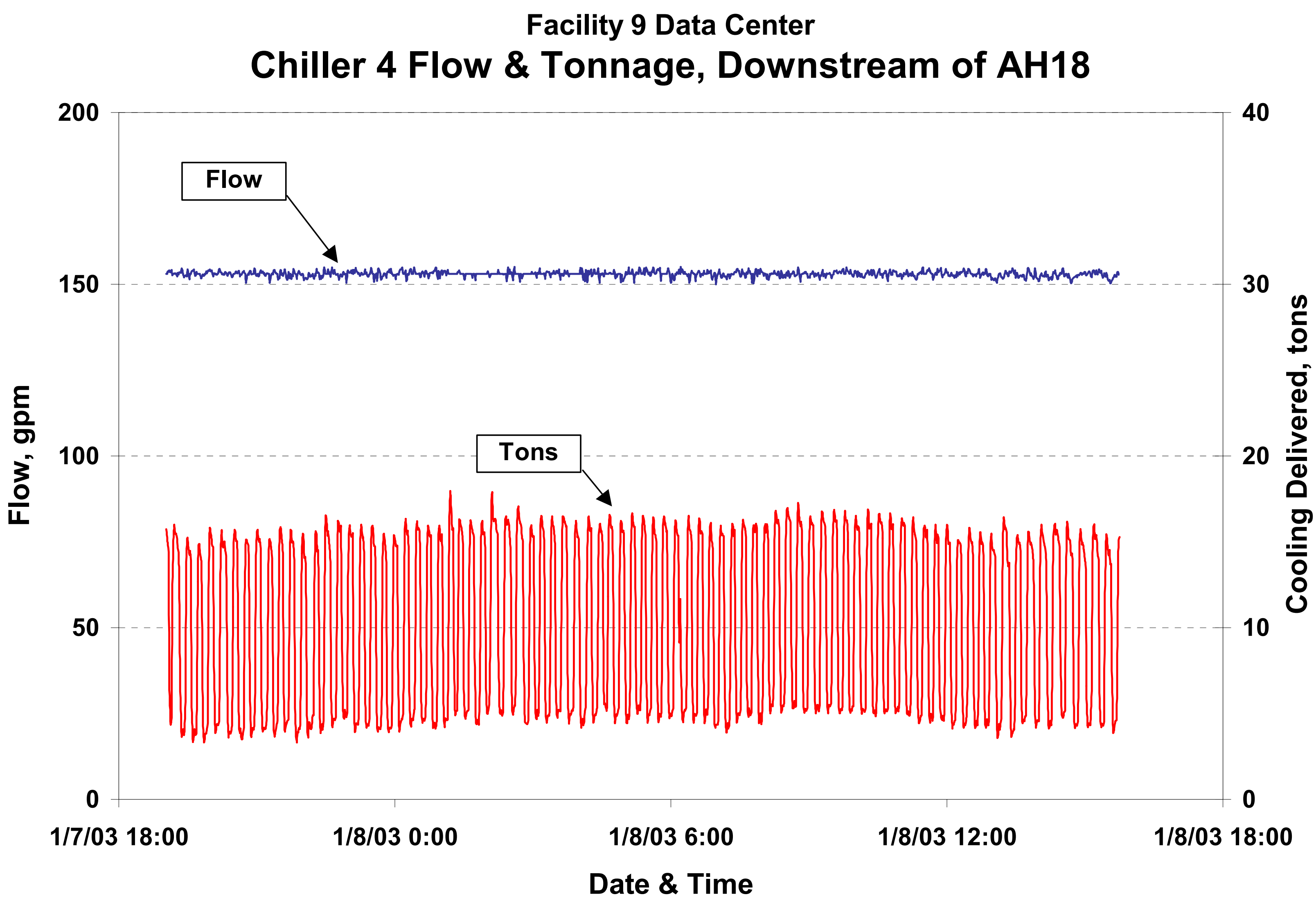
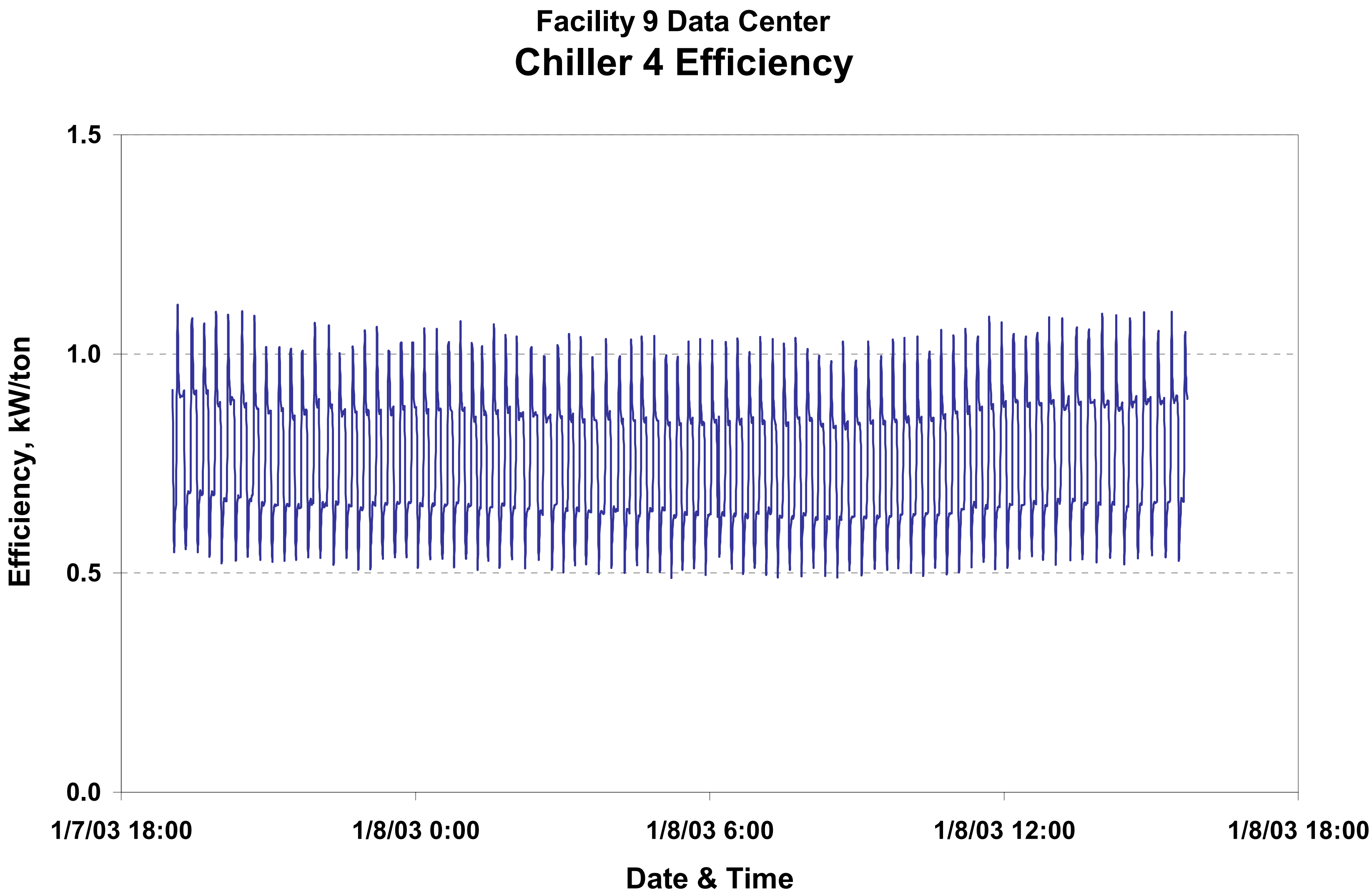
17:30
18:00
18:30
Time of Day, 1/8/03

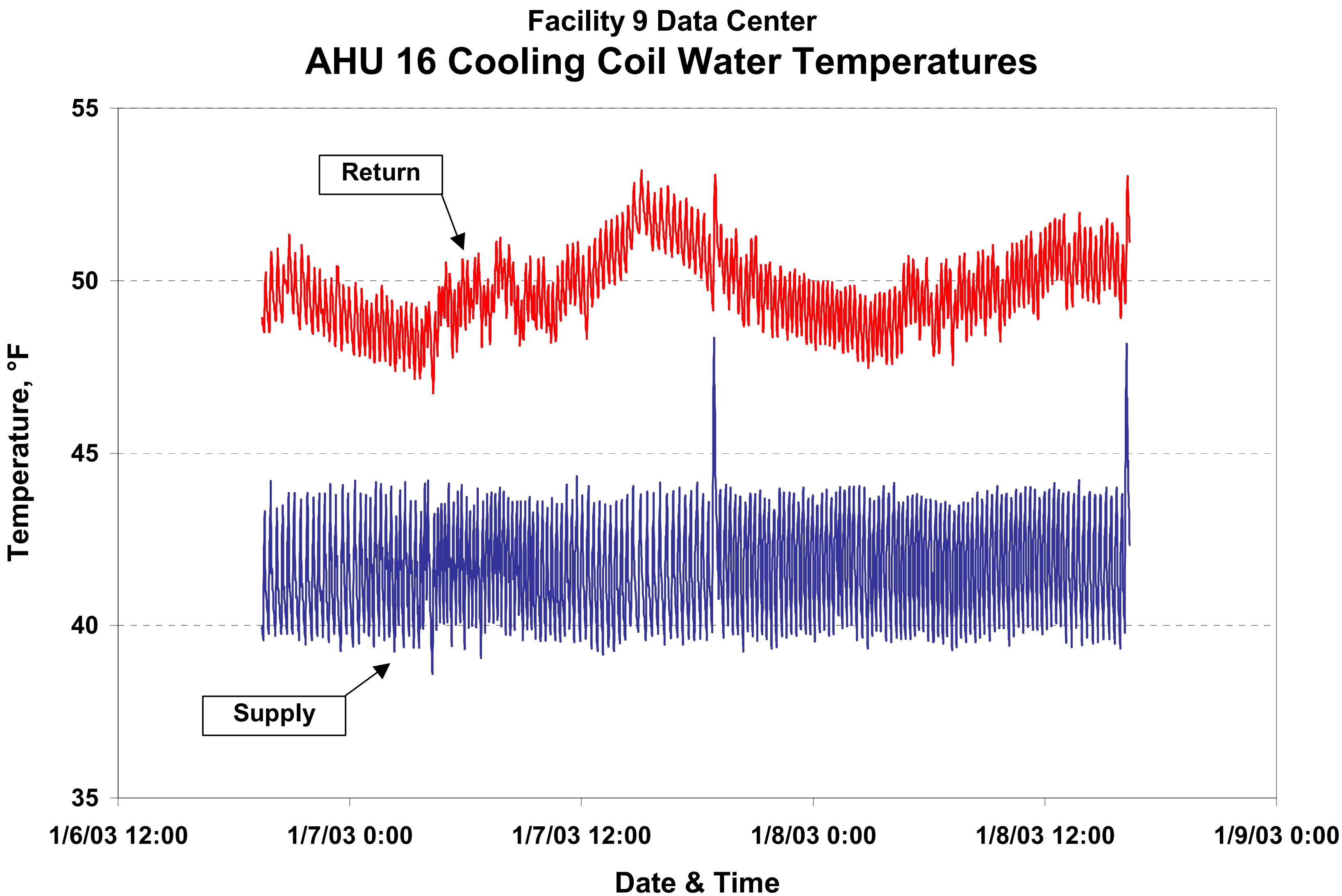

Facility 9 Data Center
Chiller 4 Temperatures
Return
Supply
50
45
40
Temperature, °F
1/6/03 12:00
1/7/03 0:00
1/7/03 12:00
1/8/03 0:00
1/8/03 12:00
1/9/03 0:00
Date & Time


Facility 9 Data Center
Chiller 4 Power
Power, kW
Power Factor
Date & Time
Power Factor
Power
100
80
60
40
20
0
1.0
0.8
0.6
0.4
0.2
0.0
1/7/03 12:00
1/7/03 18:00
1/8/03 0:00
1/8/03 6:00
1/8/03 12:00
1/8/03 18:00

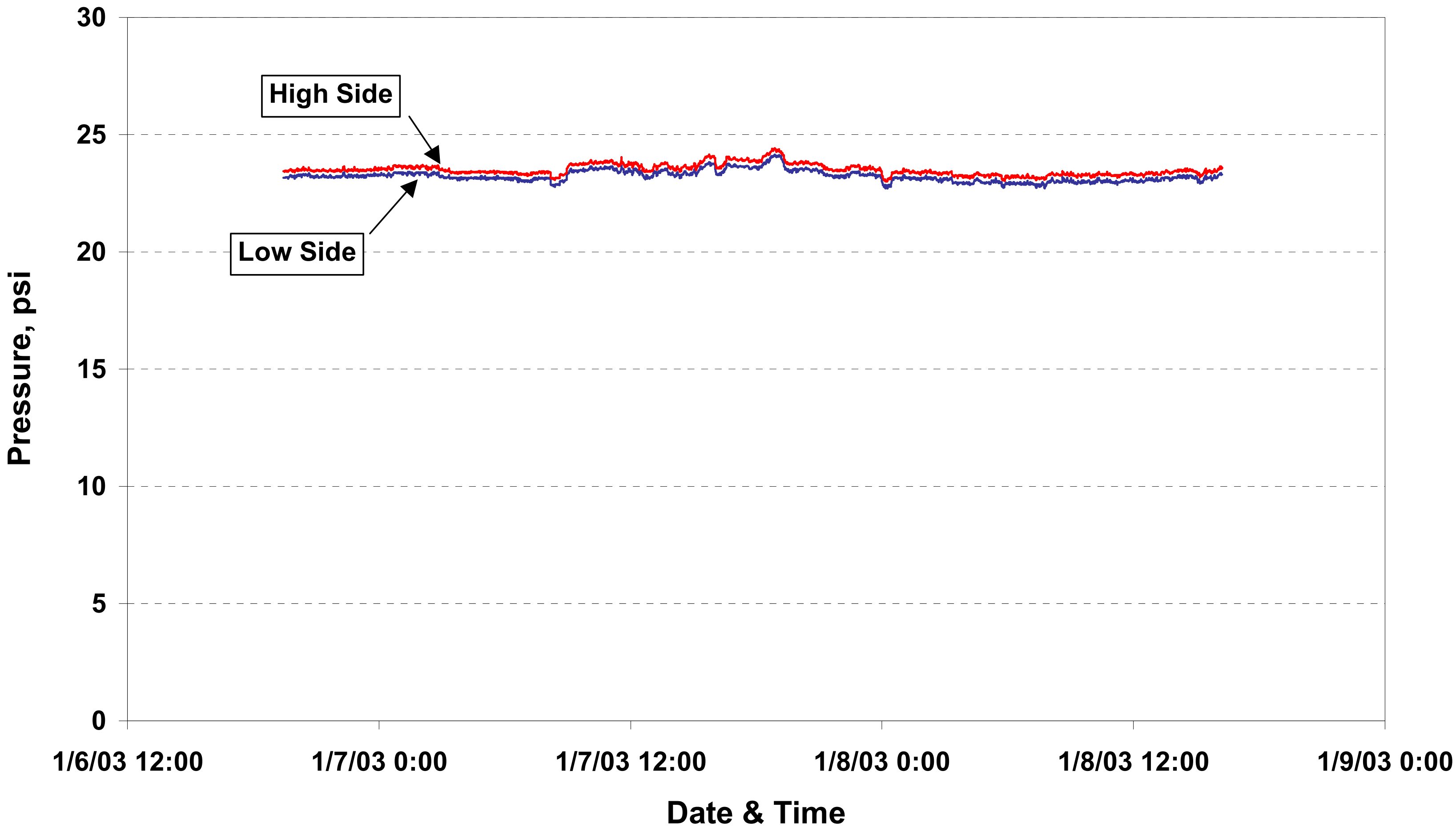

Facility 9 Data Center
Chiller 4 Flow & Tonnage, Downstream of AH18
Flow
Tons
Flow, gpm
Cooling Delivered, tons
Date & Time
200
150
100
50
0
40
30
20
10
0
1/7/03 18:00
1/8/03 0:00
1/8/03 6:00
1/8/03 12:00
1/8/03 18:00

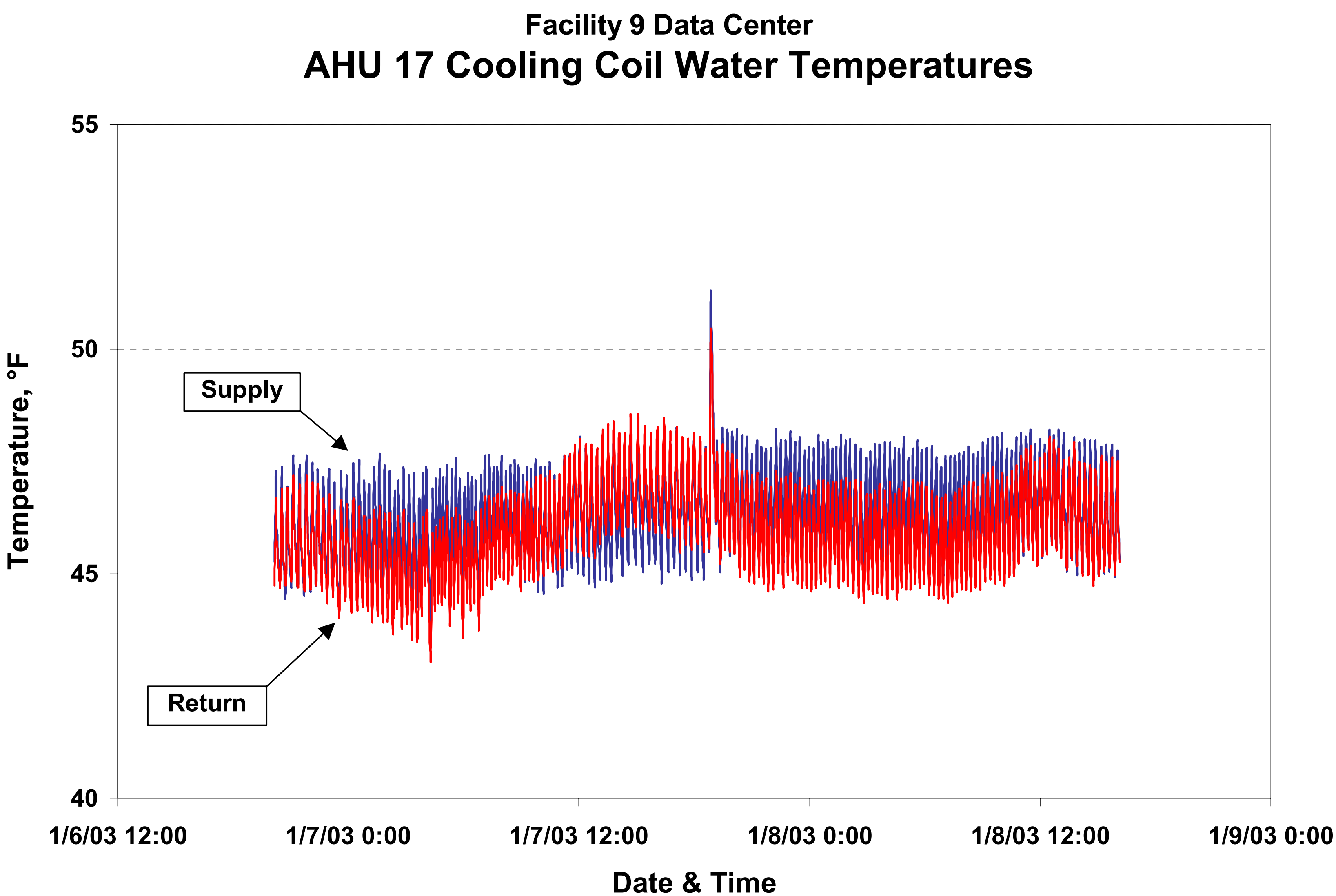


Facility 9 Data Center
Chiller 4 Efficiency
Efficiency, kW/ton
1.5
1.0
0.5
0.0
1/7/03 18:00
1/8/03 0:00
1/8/03 6:00
1/8/03 12:00
1/8/03 18:00
Date & Time


Facility 9 Data Center
AHU 16 Cooling Coil Water Temperatures
Return
Supply
55
50
45
40
35
Temperature, °F
1/6/03 12:00
1/7/03 0:00
1/7/03 12:00
1/8/03 0:00
1/8/03 12:00
1/9/03 0:00
Date & Time

Facility 9 Data Center
AHU 16 Cooling Coil Flow Setter Pressures




Facility 9 Data Center
AHU 17 Cooling Coil Water Temperatures
55
50
45
40
Temperature, °F
Supply
Return
1/6/03 12:00
1/7/03 0:00
1/7/03 12:00
1/8/03 0:00
1/8/03 12:00
1/9/03 0:00
Date & Time

Appendix B

Measurement of UPS Efficiency

UPS Measurements

ID	Input or Output	Date & Time	Source	Measurements								Calculations			
				Volts			Amps			kW	pf	Power	Effic.	Load Factor	Loss
				A-B	B-C	C-A	A-B	B-C	C-A			kW	%	%	kW
UPS-1	Input	1/7/03 14:12	UPS Display	489	486	487	267.2	259.0	289.0	-	-	227.1	89.6	40.7	23.6
	Input	1/7/03 13:53	Powersight	-	-	-	242.4	229.5	244.7	196.4	0.99				
	Output	1/7/03 14:12	UPS Display	-	-	-	-	-	-	203.5	-				
UPS-2	Input	1/7/03 14:10	UPS Display	483	482	482	164.4	164.8	164.8	-	-	35.8	47.3	3.4	18.8
	Input	1/7/03 14:02	Powersight	480	490	499	166.0	169.0	164.4	36.0	0.26				
	Output	1/7/03 14:10	UPS Display	-	-	-	-	-	-	17.0	-				
Combined	Input											262.8	83.9	16.8	42.3
	Output											220.5			

"Powersight" refers to a Powersight PS3000 power meter with 3000-amp flexible current transducers. The UPS output power wires were not accessible for direct measurement.

The above table compares Powersight readings to the UPS digital displays. The UPS displays show input power in terms of volts and amps, not kW. The input power is calculated as the average of volts times amps on each leg, times the square root of 3, times the power factor as measured by the Powersight.

The UPS display shows output power directly in kW.

There is close agreement between the Powersight and the digital display on UPS 2.

There is a 16% disagreement between the Powersight and the display on UPS 1. This is probably due to the time difference between readings; it is possible that additional computer equipment came on line between the time of the Powersight reading and the time of the display reading. The display value of 227.1 input kW is used to calculate efficiency, load factor, and loss.

Appendix C

Cooling Provided by Air Handler AH17

Air Handler AH17 Measurements

Supply Air

Diffuser/Grill Location	Date & Time	Velocity Measurements (fpm)					Flow	Temperature
		1	*2*	*3*	*4*	*Ave*	*cfm*	*deg F*
Tape Room (1 of 2)	1/8/03 13:30	82	91	83	-	85	341	56
Tape Room (2 of 2)	1/8/03 13:30	84	82	82	-	83	331	57
Main Computer Room (1 of 1)	1/8/03 13:30	82	78	82	77	80	319	55
						Total:	991	
						Ave:		56

Return Air

Main Computer Room (1 of 4)	1/8/03 13:40							71
Main Computer Room (2 of 4)	1/8/03 13:40							70
Main Computer Room (3 of 4)	1/8/03 13:40							69
Main Computer Room (4 of 4)	1/8/03 13:40							70
							Ave:	70
							Tons:	1.2

All of the air from air handler AH17 is delivered to three ceiling diffusers in the data center. Figure 2 in the report shows their locations.

Air velocity was measured with a Shortridge ADM-860 Airdata multimeter.

Temperatures were measured with a Raytek MiniTemp handheld infrared thermometer.